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TRANSACTIONS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS.

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INTRODUCTION.

Though operations of engineering, in common with all the useful arts, are practised by men in the rudest state, and become of greater and more frequent application as society improves, it is only among a people very considerably advanced in civilisation and wealth that its works can be prosecuted on an extensive scale, or with any degree of success. The only exceptions to this observation are to be found during the few and short periods in the history of the world, when it has fallen to the lot of nations to be governed by such men as Louis XIV., guided by the wisdom of Colbert and having the aid of Riquet's enterprise and Andréossy's skill; some of the kings of Sweden, who, turning their troops into excavators of canals, have in person directed their labour; Peter the Great, Frederick of Prussia, and in our own day, Mehemet Ali; princes who, whether from a singular appreciation of the true means of greatness, or with a view to facilitating their warlike measures, or as it may be in some cases, prompted by mere love of the glory to be gained, have forced works of public utility before their time in the countries under their sway. The great Languedoc canal; often repeated attempts to open a communication between the North and Baltic seas, independent of the passage through the Sound or the Belt; an inland navigation from the Neva to the Volga, the junction of the Elbe with the Oder and Vistula, and the railway now forming from Cairo to Suez, are among the peaceful trophies of these monarchs. But such desultory efforts, even when

most successful, as in the foregoing instances, stand like oases in the otherwise desert field of improvement, refreshing to meet with, but no sign of fertility in the surrounding waste; and proceeding from power in the ruler rather than will in his subjects, their effects are not of that permanent and expansive character which belongs to the voluntary undertakings of a free community.

Of such undertakings it may probably be said, without any imputation of national vanity, England offers the most splendid examples, though even among us they are of recent growth. During a long period of our history, men's minds were either wholly turned away from pursuits of this kind, or at best, their activity in them was paralysed by the excitement and uncertainty that could not but prevail when a throne was the object of struggle, and the shock of the contests so engendered was too deeply felt by the industry of the country to be recovered from in the short intervals that sometimes happened between the outbreakings of intestine war. But better times came round;—domestic quiet was established, and as the passions that had raged so fiercely gradually subsided, the people's energies no longer spending themselves in civil strife, took another and more useful direction, and the genius of commercial enterprise was called into new life.

The passing of the act of parliament for the formation of the Sankey-Brook navigation (the earliest *canal* in England) in 1755, was the beginning of a new era in the annals of internal improvement. Works of engineering, it is true, had previously been executed, some of them of considerable magnitude. Rivers had been deepened and rendered navigable, the metropolis was already supplied with water by the completion of Sir Hugh Myddleton's scheme of the New River, fens had been drained and embankments made to protect them from the inroads of the sea;—

some of these works belong to our early history. More recently, the means of at least military communication had been extended to the most remote parts of the kingdom, by the roads formed through the north of England into the Highlands of Scotland under the direction of General Wade, and M. Labelye had led the way in bridge-building on a large scale and with new methods by the construction of Westminster bridge, which was begun in 1739; while, about the same time, under the unassuming character of a country mason, William Edwards had, in the bridge of Pont-y-Pridd over the river Taaf*, set an example of intrepidity and determination that has never been surpassed. But all these undertakings, important though they certainly were, must, when viewed in connection with what has been effected since, be considered rather as the results of detached efforts, arising generally from the necessities of the individual case, and too often involving the injury or even ruin of their promoters, than as the offspring of an enlarged spirit of improvement, stimulated by the hope of gain from investment, and a well founded prospect of its undisturbed enjoyment.

Many facts may be cited in proof of the distinction here made. The very name of *adventurers* formerly given to those who undertook such hazardous enterprises evinces the feeling with which they were generally regarded, and they were of so unusual occurrence as not to furnish sufficient employment to support in the country a race of artists trained to works of the kind. If an Englishman followed such avocations, he had, from lack of work enough at home, to look for it abroad, as in the case of Perry, who so distinguished himself by the stoppage of the alarming breach in the Thames

* This remarkable bridge is 140 feet span with a rise of 35 feet, and being only 11 feet wide, has a singularly bold appearance,—stretching like a rainbow across the romantic glen below.

embankment at Dagenham in the beginning of last century, but who had had in his best days to seek in the then infant Russia the constant occupation Britain could not at that time afford him; while, on the other hand, in the drainage of the Great Fens, and many other like instances, it was necessary, in the dearth of natives competent to the duties, to bring men of skill from other countries to direct the operations, as the occasion required. By such means, however, the way was no doubt paved for the marked change that now took place in the system of public works;—the mineral productions of the country became every day more necessary for its manufacturing processes, extending on every side;—capitalists began to embark their wealth in speculations that promised a pecuniary return only, without regard to their own neighbourhood being the scene of the projected improvement, or facilities being afforded by it to their peculiar business. The change was a type of increased national means, and by the enlarged field of employment it opened up, gave rise to a new order of professional men.

James Brindley and John Smeaton were the first of this class.

Born of humble parentage in an obscure village of Derbyshire, and obliged by his situation in life to devote himself to the labours of agriculture from his earliest youth almost unto manhood, Brindley* was altogether without education, in the common meaning of the word, a want which the unceasing duties of his active life never gave an opportunity of supplying, even if the inclination existed. Guided by natural bias, he afterwards became a millwright, and in this capacity soon acquired by his mechanical skill a high provin-

* Born at Thornsett near Chapel-en-le-Frith, in 1716—died in 1772.

Chs Labelye — William Edwards

J. Smeaton — James Brindley

Robt. Mylne

John Grundy — Hugh Henshall

Robt. Whitworth — John Golborne

W. Jessop — James Watt — J. Huddart

Wm Rennie — Thos. Telford

Willm Chapman — Ralph Walker

Wm Mudbey — H. Baird

Alexander Nimmo

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cial celebrity. This, however, great though it was, might not have survived him long, or extended far beyond his immediate district, but for the fortunate occurrence which, when he had reached the age of forty, gave a new development to his genius, and turned his pursuits into a stream destined to bear his name to future ages, in proud union with one whose high rank is eclipsed by the benefits his enterprise and liberality bestowed on his country. This incident in Brindley's history was his being called by the Duke of Bridgewater to advise on his project of a canal from Worsley to Manchester. The result of the application requires not to be stated;—leaving the beaten track behind, Brindley, strong in his own powers, struck away at once into a new path, and sustained by the unflinching support of his generous patron, placed inland navigation, by one gigantic stride, so far in advance of the age, that even in the present day the works of that time may almost afford to dispense with their date, as an element in the appreciation of their merit.

Brindley's reputation was now achieved; his practice as an engineer henceforth increased steadily, and though almost wholly confined to the construction of canals, few of his profession, however varied their avocations, can boast works of equal extent or importance. Besides the Bridgewater canals, with their many miles of under-ground communications in the Worsley coal mines, their then unprecedented aqueduct of Barton, and an extent of level surface even now unparalleled; the Grand Trunk navigation, boldly penetrating through the great central ridge of England by the Harecastle tunnel, the Staffordshire and Worcestershire, the Coventry, the Oxford, the old Birmingham, and the Chesterfield canals, were all designed, and with one exception executed by Brindley;—and thus, though he had watched over the cradle of inland navigation, a communication by means of it was established by his labours between places so distant and divided by natural barriers as London, Liverpool, Bristol and Hull; while, by his success, the far more

important object of awakening public attention to the advantages of canals was also fully attained.

Smeaton's* happier lot exempted him from the struggle with adverse circumstances in early life, which his great contemporary had to encounter. Springing from the middle ranks, he had the advantage of a fair education, and, save the sacrifice of a short time to legal studies, in compliance with a parent's wish, fortunately there was nothing to thwart the bent of his genius, which soon showed itself decidedly. Established in the metropolis as a philosophical instrument maker, he gained the notice of the scientific world by his ingenuity, and by several communications to the Royal Society on mechanical subjects, and so high had he raised himself in estimation, even when engaged in such pursuits, that though untried and unknown as a practical engineer, he was selected as the fittest person to be entrusted with the rebuilding of the Edystone lighthouse when it was destroyed by fire. This, Smeaton's first work, was also his greatest;—probably, the time and all things considered, it was the most arduous undertaking that has fallen to any engineer, and none was ever more successfully executed,—and now, having been buffeted by the storms of nearly eighty years, the Edystone stands unmoved as the rock it is built on, a proud monument to its great author. Buildings of the same kind have been executed since, but it should always be borne in mind who taught the first great lesson, and recorded the progressive steps of his work with a modesty and simplicity that may well be held up as models for similar writings. His reports are entitled to equal praise,—they are a mine of wealth for the sound principles they unfold, and the able practice they exemplify, both alike based on close observation of the operations of Nature, and affording many fine exam-

* Born at Austhorpe near Leeds, in 1724—died in 1792.

ples of cautious sagacity in applying the instructions she gives to the means within the reach of art.

Strange though it may now seem, Smeaton's rise in the profession for which he had so signally proved his qualifications, was not at first rapid, but amid the rage of public works that then grew up, the man who had built the Edystone lighthouse could not be long passed by, and once fairly launched in general practice, he soon became connected more or less with almost all the great improvements then in progress, contributing largely to the advancement of engineering in every branch. The bridges of Coldstream, Perth and Banff, the Forth and Clyde ship canal, the Aire and Calder, the Fosdyke, and other navigations and drainages in the fens as well as elsewhere, and the harbours of Rye, Ramsgate (the grand pattern of artificial harbours) and Portpatrick, with important though not so extensive operations in many other ports, rank among his leading works, but give no idea of the extent and variety of a business altogether without equal in that day, and rarely surpassed since; for besides being as it were the great *standing counsel* of his profession, to whose judgment all doubtful questions were submitted, he was constantly employed in carrying his own measures into effect, and his execution was attended with such success that, on the occasion of the solitary failure by which it was marred, we find him lamenting it can no longer be said, that " in the course of thirty years' practice, and engaged in some of the most difficult enterprises, not one of Smeaton's works had failed!" But his genius and resources were not wanting to him even in Hexham bridge;—it was in the operations designed to avert the dreaded catastrophe, when the foundations of that structure began to give way, that the diving-bell was first brought into the service of the engineer.

Such were the fathers of British engineering. Among their worthy associates were Grundy, who, in addition to many works of

navigation and drainage, particularly in the fens of Lincolnshire and in Yorkshire, introduced docks in the Humber by the construction of the Old dock at Hull;—Henshall, Brindley's brother-in-law and fellow-labourer in most of his undertakings;—Semple, who built Essex bridge over the Liffey in Dublin;—Mylne *, for many years engineer to the New River Company, who began his professional life as the architect of Blackfriars bridge in London, and was also the original engineer of the Eau Brink cut and the Gloucester and Berkeley canal;—Golborne, an authority in his day in the treatment of rivers, of his success in which the Clyde is a favourable specimen; and Whitworth, engineer of several important canals, of which the Thames and Severn may be named as one, and who has the merit of having designed and executed the Kelvin aqueduct on the Forth and Clyde canal, a great work at that time:—all these names deserve honourable mention, though in this brief retrospect a passing notice only can be bestowed on them.

William Jessop † claims to be more particularly alluded to. This excellent man held an intermediate place in time between what may be considered the first and second generations of civil engineers, and he was the first of his profession that can be said to have been regularly bred to it. The pupil, and afterwards for several years the confidential assistant of Smeaton, he was reared in the best

* Born in Edinburgh, in 1734—died in 1811.—Robert Mylne may be looked on as the last practitioner of note, who combined in a considerable degree the avocations of the engineer and the architect. The professions have since become almost entirely disjoined, but the study of architecture ought still to form a branch of the engineer's early discipline, for though utility and strength are no doubt the main objects of his practice, the works are few that may not be benefited by the application of taste, without sacrificing those essential characteristics.

† Born at Plymouth in 1745—died in 1814.

school, and it is not paying any niggardly tribute to his abilities and character, to say, that his subsequent career shed no discredit on his great master. His extensive practice consisted chiefly, though by no means exclusively, in works connected with navigation and drainage. The magnitude of his labours in these is attested by the improvements on the rivers Aire and Calder and the Trent during the time he held the appointments of engineer to those undertakings, by many of the numerous navigations intersecting the midland counties, by the great work of the Grand Junction canal connecting the central districts of England with the metropolis, by the inland navigations of Ireland on which he was the principal adviser, and by the City ship canal across the Isle of Dogs;—while in the Surrey iron *rail* or rather *tramway*, which, though not successful as a speculation, deserves notice as one of the earliest applications of this mode of conveyance to the purposes of public traffic, and in the conversion of the part of the river Avon through the city of Bristol into an immense floating dock, with the bridges and other structures accessary to it, he appears equally at home in other walks. These are the principal works which were more directly Jessop's;—he was besides consulting engineer of the West India Dock Company in London, and of the Ellesmere Canal Company, and indeed from standing at the head of his profession for several years after the retirement of Smeaton, he was called in on most of the great schemes then in agitation, and also engaged in their execution, but they will be mentioned in connection with the men more immediately concerned in them, and to whom they are more usually ascribed, if not in a greater degree due. Any other course would evidently be quite out of place in a paper of the nature of the present, the object of which can with propriety only be to indicate generally the works on which different engineers have been employed, not to pronounce on the individual share in them falling to each.

The second race of engineers now began to take their part more conspicuously on the stage. By the exertions of their predecessors, Britain had already gained a high reputation for her public works;—the support of the national fame in this respect was now to pass into other and younger hands, among whom Rennie and Telford were early distinguished. A wide field of labour lay before them. Works which had been begun but a very few years before were now yielding their profits, in many instances to the individuals who had originally embarked in them, and their success allured others to like adventures;—the operation of this cause alone would have much enlarged the bounds of professional employment,—the public relations of the country extended the opportunity further. What had been done hitherto was chiefly the result of private enterprise;—this great moving force was still left free to act, and indeed was strengthened by men in authority more than before, while another power of only inferior intensity was superadded to it:—works of unparalleled magnitude were now undertaken by government, both for the internal improvement of the country and as contributory means to its external defence, and in such works some of the engineer's proudest triumphs are to be found.

John Rennie* occupied a foremost place in maturing and executing these mighty projects, public and private, and his previous training had admirably qualified him for the duties they required He displayed almost in childhood the mechanical bias that marked his future character, and whether as the apprentice of the ingenious Meikle, the inventor of the threshing machine, or as an occasional student under some of the most celebrated of the men by whose labours the university of Edinburgh acquired fame throughout Europe, all his subsequeut pursuits tended in the direction that was to lead him

* Born at Phantassie in Haddingtonshire, in 1761—died in 1821.

to eminence. He began business as a millwright in his native county, but was soon after led to change the scene of his busy life, in consequence of an introduction to James Watt *, who invited him to the capital to superintend the erection of the Albion flour-mills, by which and other works in the same line, undertaken on his own account in quick succession, he soon acquired reputation as a very superior mechanist, and in the year 1791 or 2, he was appointed to direct the execution of the Lancaster canal. This and the Crinan ship canal (insulating the isthmus of Cantire in Argyleshire) with which he was entrusted about the same time, were his first essays in civil engineering, and by the greatness and difficulty of some of their works, (as the fine aqueduct over the river Lune in the former, and the massive rock excavations of the latter,) they afforded an excellent opportunity of testing his skill.

Rennie soon became firmly established,—the government of the land afterwards ranked among his clients,—the three kingdoms bear witness to the extent of his subsequent labours. The navigations already mentioned, to which the Kennet and Avon and the Portsmouth canals fall to be added; the completion of the Eau Brink cut and the project of the new Nene outfall for the improvement of drainage in the immense fens of Norfolk, Lincoln and Cambridgeshire ; a participation in a greater or less degree in the formation of three of the large dock establishments in the port of London, with Leith docks and extensive additions to those of Liverpool and Hull, for commercial purposes ; the still more stupendous undertakings in aid of war at His Majesty's dock-yards, especially Sheerness, raised by him out of a quicksand five-and-twenty feet deep and ten feet under low water, and Pembroke, which he hardly lived to see com-

* Born at Greenock, in 1736—died in 1819.—In early life Watt himself practised as a surveyor and engineer, and had he continued in the profession, would in all probability have taken the lead;—a more glorious immortality awaited him, but no one has contributed more essentially to the progress of engineering than that illustrious man, from the facilities, before unknown, given by his steam-engine to its operations.

pleted; the breakwater in Plymouth Sound, the artificial harbours of Kingstown, Howth, Holyhead and Donaghadee, and two great bridges over the Thames, in the heart of the metropolis, with the design for a still nobler third, built since his death, and other bridges in the country, of which that over the Tweed at Kelso and Wellington bridge in Leeds particularly challenge notice,—all these were wholly or in chief part produced by Rennie, and they by no means exhaust the list of his works, of which the variety, magnitude and importance need not be expatiated on after such an enumeration.

The name of Rennie naturally suggests that of his compeer, Telford, though in the few short years that elapsed between their deaths, the grave also closed over more than one other that cannot be passed unnoticed even in the most cursory review of this kind.

In the person of Thomas Telford * another striking instance is added to those on record of men who have, by the force of natural talent, unaided save by uprightness and persevering industry, raised themselves from the low estate in which they were born, to take their stand among the master spirits of their age. A native of the pastoral district of Eskdale, he received the education commonly given to the peasantry of that country, and was at an early age apprenticed to a stone-mason in the neighbouring village of Langholm, with whom he remained until his twenty-third year. The New Town of Edinburgh was then in progress, and thither Telford bent his steps, led probably by the prospect of employment in the works of that improvement. Returning to his native border at the end of two years, he found there too bare and narrow a sphere of action for his already aspiring mind, for while plying his trade he had not neglected to cultivate his understanding, and he now felt conscious of powers fitting him for a higher destiny. He came to London,

* Born at Westerkirk in Dumfriesshire, in 1757—died in 1834.

where after working for a time as a mason in the quadrangle of Somerset House, then building, his superior intelligence attracted notice, and he was appointed to superintend the erection of a new official residence in Portsmouth dock-yard, which occupied him until 1787. He then, on the invitation of Sir William Pulteney, himself a borderer*, undertook the direction of some alterations in Shrewsbury Castle, and was soon after elected county surveyor of Salop, a situation he held to the day of his death. In this official capacity bridge-building chiefly claimed attention,—a short time added another important branch to his avocations: —in 1793 he was nominated acting engineer of the Ellesmere canal, and thus was Telford fully introduced to the practice of a profession he was in a few years to take so distinguished a lead in. The road to fame was now open before him, and he never lost sight of the goal.

There is hardly a corner of Great Britain that does not contain some record of Telford;—his services were required by the Crown, and foreign powers also availed themselves of his skill, at least in one memorable instance, the great ship canal of Göta in Sweden, the last connecting link in the navigation from the Baltic sea to the German ocean through the Swedish lakes. The Caledonian canal (originally proposed, along with the Crinan canal, by Watt to the Commissioners of Forfeited Estates, and also advised on by Jessop, though its execution was under Telford's charge) is a work of similar character in our own country, and with it may be named the Gloucester and Berkeley canal, before mentioned in connexion with Mylne, which, though not of equal magnitude or difficulty, is also adapted for sea-borne vessels of large tonnage, and has made the inland city of Gloucester a port for foreign trade; while the Ellesmere canal, already alluded to, with its bold aqueducts of Chirk and Pontcysylte, in which also he was associated with Jessop, the Shrewsbury canal, the Birmingham

* Of the family of Johnstone of Westerhall.

and Liverpool Junction canal, with extensive improvements of the old Birmingham canal, and also of the navigations through the district of the Fens, are among the other important additions made by Telford to internal water communication. The improvement of the river Clyde to an extent little contemplated in the days of Golborne, the numerous harbours for fisheries in the northern coasts of Scotland, Aberdeen and Ardrossan harbours, the harbour and docks of Dundee, Saint Katharine's docks in London, the Glasgow waterworks, several bridges over the Severn, especially those of Tewkesbury and Over at Gloucester, Broomielaw bridge over the Clyde, and Dean bridge in Edinburgh, swell the catalogue of only his principal undertakings. But the works which will perhaps appear of most moment to a mind looking at the consequences to civilisation, are the great systems of roads,—the Highland, the Holyhead, and the Glasgow and Carlisle, by which, but especially the first mentioned, whole regions were brought as it were within the pale of society; while their thousands of bridges, including among them such structures as those of the Menai and the Conway, Dunkeld, Craig-Ellachie and Cartland-Craigs, with the enormous cuttings in the sea-cliffs of North Wales, attest their greatness in an engineering point of view.

The foregoing sketch, though slight, may enable some judgment to be formed of the services rendered to their country by Telford and Rennie respectively. In looking back upon their professional achievements, it is pleasing also to reflect on the high respect with which they were regarded in their lifetime,—both employed by the king's government in its various departments, alike enjoying the almost unlimited confidence of the public for a long series of years, and in going down to the grave, meeting with equal honour:—while Rennie's remains lie "tombed beneath" the magnificent canopy of Saint Paul's Cathedral, Telford's "ashes found their latest home" within the venerable walls of Westminster Abbey.

Contemporary with these eminent men flourished Ralph Walker*, who, having been a sailor for twenty years, and a West India planter for fifteen more, became an engineer at the age of fifty, and was engaged with Jessop in the formation of the West India docks in London, the design of which he had originally proposed, as also that of the East India docks, which too, in conjunction with Rennie as consulting engineer, he carried into effect, and afterwards constructed the East London waterworks, displaying throughout these and other similar undertakings he was employed on, a peculiar happiness in mechanical contrivance, of which his introduction of the double *swing* bridge may be mentioned as an instance;—William Chapman†, whose works are to be found in Newcastle bridge and several harbours and canals, particularly the harbours of Leith and Seaham, the Sheffield canal, and in cooperation with Jessop, the Grand canal from the Liffey to the Shannon, and who, besides bringing the skew principle of bridge-building into practice in this country, if indeed he did not discover it, contributed largely to the diffusion of professional knowledge by a series of valuable papers on engineering subjects;—Hugh Baird, the engineer of the Edinburgh and Glasgow Union canal, with the three large aqueducts of Avon, Linlithgow and Slateford, works of admitted merit, and who, not knowing until years after even that such an idea had occurred to that able French engineer, M. Perronet, changed the old draw-bridge with its overhanging levers and chains into the modern *lifting* bridge, some of the originals of which still exist in the Forth and Clyde canal;—Joseph Whidbey, the original projector of Plymouth Breakwater, and Rennie's coadjutor in the construction of it; and Alexander Nimmo, the civil engineer principally employed by

* Born at Tullibody in Clackmannanshire, in 1749—died in 1824.

† A native of Whitby—died in 1830.

government in Ireland, where he conducted works of considerable extent undertaken for the internal improvement of that country, and similar in character to those executed by Telford in the Highlands of Scotland, Dunmore harbour near Waterford and Wellesley bridge at Limerick being the chief of them. And to this list may justly be added Captain Huddart*, who though not a professional engineer, evinced a rare mechanical genius, and having most deservedly a high repute for nautical knowledge, was much consulted respecting harbours and navigable rivers, his skill in the treatment of which no one appreciated more fully than the distinguished practitioners with whom he was joined in many such questions.

The leaders under whom engineering gained the honourable standing it has held for years have now been reviewed. To continue the enumeration so as to include living practitioners is no part of the present design; though by following this rule the opportunity is lost of glancing at the progress of the great revolution which the locomotive engine is so rapidly effecting in the internal communications of the country. Neither does it fall within its scope to go into any detail of those, now numbered with the dead, who have been distinguished in the collateral branches of mechanism;—the merits of their labours are fully recognised, as how can they be otherwise, when a Watt, a Maudsley, and a Bramah are at their head?—but the present limits confine attention to those, strictly *civil engineers*, and to their works in that capacity, works which will continue to excite admiration while any taste is left for what is noble in object, fitting in design, and grand in execution.

* Born at Allonby in Cumberland, in 1741—died in 1816.

It remains to say a few words of the associations that have been formed for promoting intercourse and knowledge among engineers, and especially of the Institution from which this work emanates.

When the Royal Society was established, its views embraced the whole range of mathematical and physical knowledge, and it continued for more than a century to be the only public body in England devoted to such pursuits, but as the objects of philosophical research multiplied and their cultivation became more widely diffused, the tastes and avocations of individuals inclined them to different studies, and the division of employment so requisite for the perfection of the arts was found equally to apply to science. The Astronomical Society was the eldest branch from the parent stem; associations for the specific promotion of Geology, Botany, Zoology, Geography, Statistics, and indeed almost every department of scientific and literary enquiry, have followed in quick succession, and these bodies confining themselves to the definite objects of their institution, are enabled to follow them out with a detail that scarcely falls within the more general scheme of the Royal Society. But such a subdivision is not limited to pursuits of what may be considered an abstract character,—it is equally advantageous in the applications of science to purposes more immediately practical, and becomes daily more so from the growing intelligence

and number of those engaged in them. Associations of professional men have accordingly sprung up, Medicine and Surgery taking the lead, as from their paramount importance they were entitled to do, and now presenting many flourishing societies.

The Institution of Civil Engineers is of more recent origin than most of the societies above alluded to; but the profession itself is not of ancient date, and while it was still young its members adopted the principle of union. Their first society, or rather club, was established under the auspices of one of the earliest and greatest of them, the illustrious Smeaton, in 1771, and reorganised in 1793;—its history is given in the preface to Smeaton's Reports, which were published by a sub-committee of its members. The body still exists, under the name of the "Smeatonian Society of Civil Engineers," meeting monthly during the session of Parliament at the Freemasons' tavern, and includes, as it has done from its foundation, some of the most eminent men in the profession, with associates from the ranks of general science. But though this society had so far answered a good end, its constitution was of too exclusive a nature to meet the wants of so large and mixed a body as soon became engaged in engineering, and a feeling began to be generally entertained that in addition to it, an institution on a larger scale, having for its object the furtherance of professional knowledge, might be made eminently useful, and was indeed due to the profession from those engaged in it.

This opinion was held by the late Thomas Telford (himself a Smeatonian) among others, and an opportunity ere long occurred of giving it practical effect.

It was towards the end of the year 1817 that a few gentle-

men *, then beginning life, impressed by what they themselves felt with the difficulties young men had to contend with in gaining the knowledge requisite for the diversified practice of engineering, resolved to form themselves into a society for promoting a regular intercourse between persons engaged in its various branches, and thereby mutually benefiting by the interchange of individual observation and experience. The first meeting of the embryo society was held at the King's Head tavern in Cheapside on the 2d of January following, when a series of rules was adopted for its government, and these rules were, and with some modifications and additions continue to this day to be the basis of the fundamental laws of the Institution of Civil Engineers, which indeed dates it birth from this meeting.

The society continued to assemble in like manner during the period allotted to its session for two years, without however any considerable increase of members or change of circumstances. But a resolution passed on the 23d of January, 1820, led to more important consequences;—it was as follows:

> " That in order to give effect to the principle of the
> " Institution, and to render its advantages more general both
> " to members and the country, it is expedient to extend
> " its provisions to the election of a President whose exten-
> " sive practice as a Civil Engineer has gained him the
> " first-rate celebrity; and that a respectful communication
> " be made to Thomas Telford, esquire, civil engineer, to
> " patronize the Institution by taking upon himself the office
> " of President."

* Messrs William Maudsley, Henry R. Palmer, Joshua Field, James Jones, Charles Collinge and James Ashwell.

So little was the society known up to this time, that Telford had never heard of its existence when the foregoing resolution was announced to him, but appreciating with characteristic judgment the value of such an institution and the useful results it was capable of yielding, he accepted the proffered chair without hesitation, and was formally installed on the 21st of March following. His observations on that occasion were marked by the strong sense he always brought to bear on any subject he applied his mind to, and as they evince in clear and simple language the view he took of the principles essential to the prosperity of the association,—principles which it is the earnest desire of those now entrusted with the management of the Institution to follow out in their fullest extent,—it may not be altogether irrelevant, even at this distance of time, to quote here a portion of his inaugural address.

> "It is my duty as President," he said after a few words of preface, "to offer some remarks on the nature of the "Institution and its probable results. They shall only be "few and short, it being I trust sufficiently apparent that "the principles of the Institution rest more upon practical "efforts and unceasing perseverance, than upon any ill-judged "attempts at eloquence.
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> "Having had no share in or even knowledge of the "original formation of this Institution, I can speak with more "freedom of its merits. It has in truth, like other valuable "establishments of our happy country, arisen from the wants "of its society, and being the result of its present state promises to be both useful and lasting."
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> "From a view of the topography and statistics of this "country, it is quite evident that civil engineering has in-

"creased to an extent and importance which urgently demand "such a separate establishment as you, its earliest members, "have so judiciously planned, and by meritorious persever- "ance brought to its present state.

"I have carefully perused the rules and orders, which have "been prepared with much attention, and I think they are "now sufficiently matured to be a guide and guard for the "conduct and welfare of the Institution. Judicious regulations "are absolutely necessary in all societies, but I trust that in "this the good sense of the members will always prove "that manners and moral feeling are superior to written "laws, and will render my duty as President both easy and "pleasant.

"In foreign countries similar establishments are insti- "tuted by government, and their members and proceedings "are under its control, but here a different course being "adopted, it becomes incumbent on each individual member "to feel that the very existence and prosperity of the Insti- "tution depend in no small degree on his personal conduct "and exertions; and the merely mentioning the circumstance "will, I am convinced, be sufficient to command the best "efforts of the present and future members, always keeping in "mind that talents and respectability are preferable to num- "bers, and that from too easy and promiscuous admission, "unavoidable and not unfrequently incurable inconveniences "perplex most societies."

Telford's name gave a new impulse to the progress of the Institution, which grew rapidly in importance under his fostering hand, until on the third of June, 1828, it received a Charter of Incorporation under the Great Seal, by the title of the "Institution of

Civil Engineers." By that act of royal grace its standing was confirmed, and its prosperity has since been uninterrupted by any untoward event, save the lamented death of its great President. The circumstances under which he became connected with the Institution have been detailed. A few years after, he began to contract his engagements, and as he gradually withdrew from the toils of business, his attention became more and more concentrated on this, as it were, his only child and the last object of his solicitude; the care of which gave employment to his mind in the evening of his days, free from the too violent excitement apt to be produced by the active duties of professional life. The rising society then occupied much of his time and more of his thoughts,—its collections were enriched by his bounty,—and when, full of years and honours, he felt the close of life approaching, he endowed the Institution with a munificent bequest.

Considering the debt of gratitude the Institution owes to Telford, a memorial of his life and works in some detail would not be inappropriate, and may indeed be expected in this place, but as the valuable account written by himself is now on the eve of publication, it has been thought better not to attempt in an imperfect manner what that interesting work will supply so amply; especially as in the preceding short review of the leading engineers who have flourished in England, he is shown in due relation to his professional brethren, and there is neither wish nor, for one standing so high, necessity that he should be more. The feeling towards him of the body he so worthily presided over is better shown by the readiness with which its members (along with others, some of them of exalted rank, who properly value his public services) have come forward individually as subscribers to the monument on which the classic chisel of Baily is now engaged.

The Charter of Incorporation and the Regulations of the Institution enacted under it, with the official lists in the appendix annexed to this volume, exhibit the objects, constitution and present strength of the body. A statement of the means such a society must possess of advancing professional knowledge, can hardly be necessary. An important one is the depository it maintains for the reception and preservation of documents which, on the demise of their original owners, either become the property of private individuals of widely different pursuits, to whom they are of comparatively little value, or are too often altogether lost. Among the contributions which have thus been made to the archives of the Institution, the original papers and drawings accumulated during his long practice, and his professional and scientific library as bequeathed by the late President, deserve to be particularly named;—also a complete set of the reports of William Chapman, civil engineer, handsomely presented by his surviving brother; and the very valuable and extensive collection of works and manuscripts relating chiefly to inland navigation, which belonged to Colonel Page, of Speenham-land in Berkshire, and for which the widow of that regretted gentleman, who ranked among the honorary members of the Institution, is entitled to the warmest thanks.

The several departments of the Government have likewise shown their willingness to do what they properly can to promote the interests of the Institution, and the Council have peculiar pleasure in making this public acknowledgment to his Excellency the Lord Lieutenant and the Chief Secretary of Ireland, and to the Master General and Board of Ordnance in England, for their liberality in directing sets of the invaluable ordnance maps of the United Kingdom to be presented so far as published, and to be continued as subsequent sheets appear.

The Telford legacy of £2000, with a residuary interest which it is understood will enhance the amount very materially, has placed in the hands of the Institution another powerful means of forwarding its objects. The interest of the fund is directed "to be expended in annual premiums under the direction of the Council;"—some of these have been already awarded, and it is to be hoped that the inducement they hold out may lead those, particularly young engineers, who have time and opportunity, to keep accurate drawings, models and descriptions of works and machinery erected in different parts of the kingdom, with a view to their being presented to the Institution. The Council will mark in an especial manner all efforts of this kind, for by such only can the reproach be removed, and reproach it must be considered, that in a country possessing so many interesting works in the department of the civil engineer, it is almost vain to look for any record of them as actually performed.

The present volume contains a selection from original communications that have been made from time to time. The choice of the papers has been regulated entirely by the practical usefulness and interest of the subjects treated of, without the least regard to merit of composition, to which it is plain no claim can or need be laid by a work dealing with matters in their nature hardly susceptible of the embellishments of style, and proceeding from men engrossed with pursuits little conducive to the cultivation of literary habits. It will also be understood that the publication of an article does not imply any guarantee of the accuracy of the facts stated, or any approval of the arguments and theories brought forward;—all these must of course rest on the credit of the respective authors, the Council's responsibility being limited to the circumstance of the papers inserted being calculated to promote the general purposes of the Institution. With the same view, in one instance in

which there was no communication in a form fit for publication, it being thought proper from the interest of the work* not to postpone a notice of it, as perfect an account as possible has been compiled; and this, it may be observed, is the only case in which recourse has been had to the conversational discussions, in which a great part of the proceedings at the ordinary meetings consists, and of which copious reports are recorded in the minutes, supplying a mine yet to be worked, and open to every class of members.

With these observations, the Council beg to present the first volume of the Institution's Transactions. To go into the causes that have prevented an earlier appearance would be to occupy the public with circumstances now of little importance,—some of them, to be found in the nature of the engineer's occupations and habits, have been already alluded to. A beginning has, however, at length been made, and surely it is not indulging in too sanguine a hope to anticipate that it will be energetically followed up, in a country depending so much as this does for the continuance of its power on the progress of the mechanical knowledge which it is the truly national object of this Institution to promote.

* Grosvenor Bridge at Chester.

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TRANSACTIONS.

I. *An Account of the Harbour and Docks at Kingston-upon-Hull. By* Mr. Timperley, *Resident Engineer to the Hull Dock Company. Communicated by the* President, James Walker, Esq., *F.R.S., L. & E.*

THE OLD HARBOUR.

The river Hull, according to Mr. Tickell, the historian of the town, formerly discharged itself into the Humber between Drypool and Marfleet, and that part of the present river usually called the Old Harbour, was originally no more than an open drain cut by Lord Sayer of Sallon, for the purpose of draining the country.

This harbour, from the north bridge to its junction with the Humber, was the original and, previously to the construction of the docks, the only port for the town; its direction is nearly north and south, its length from the bridge to the end of the Garrison Jetty, 2940 feet, and the average width within the staiths, at high water of spring tides, 165 feet; the area is therefore about eleven acres, and the depth is 22 feet.

As trade and commerce increased, the harbour became insufficient to contain all the vessels that frequented the port, many of which were therefore obliged to receive and deliver their cargoes whilst lying in the roads, by means of craft, and so crowded was it at times, that even up to the period of the Junction Dock being made, ships have been known to be twenty tides or more in passing from the Humber to the Old dock. But the crowded state of the harbour, and the consequent delay in getting to and from the quays, were not the only inconveniences; for, from its being an open tideway, all vessels draw-

ing more than four or five feet water grounded every tide; so that damage was frequently sustained, particularly by such as were sharply built and deeply laden. Complaints were also made by the officers of the Customs from time to time, of the great risk and difficulty in collecting the duties, whereby, it was stated, the revenue suffered very materially, and this ultimately led to the formation of the Old dock.

It should also be observed, that for some hours before low water, the current is so strong as to be unnavigable for vessels against the tide, and those passing with the stream are frequently injured; the fall or declivity from the outer end of the Old dock basin to the harbour mouth, at low water spring tides, being in general from four to five feet, and sometimes more, and the velocity of the ebb at such times from three to four miles an hour.

Before the Old dock was begun, transverse sections were taken of the harbour by Smeaton and Grundy, from which we find that the depth of water is now about the same as it was at that time, but the river is much narrower near its junction with the Humber; this diminution in the width has taken place since the Humber dock was made, from the free course of the tide, obstructed and retarded by the projection into the river of the quays and piers of the basin, causing a great accumulation of mud upon the shore for a considerable distance, both above and below the entrance to the Humber dock: and the mouth of the harbour has not only been narrowed by these works, but has been extended further into the Humber, and a new direction considerably to the westward given to it.

The harbour is scoured entirely by its back waters, of which the principal supply in summer is from the river Hull, which extends into the East Riding about twenty miles, and is navigable for vessels of fifty tons' burden; but in winter, the drainage from the extensive level of the Holderness and the low land on the west side of the river, has been, for a long time, a very powerful auxiliary in maintaining the depth.

For the convenience of vessels entering, two dolphins have been erected upon the Humber, to the east of the harbour mouth, the last in consequence of this part of the beach sanding up, as before noticed; and there is a jetty or small pier with the necessary mooring posts, and two transport buoys a little to the south of the dolphins. In former times a chain was stretched across the entrance of the harbour, and a small charge made for all vessels passing in or out, but this restriction and impost have been discontinued for many years.

On each side of the harbour, for nearly its whole length, there are staiths or platforms, fifteen feet wide, for loading and delivering vessels; they are private property, and in order not to obstruct the free course of the tide, are (in pursuance of an act of parliament) formed of large piles driven firmly into the ground, upon which are laid transverse beams, covered with close planking. Cranes are fixed on these staiths, and on the town side there is an extensive range of private warehouses for sufferance goods.

Tides. The time of high water at Hull, at the full and change of the moon, is six o'clock, but the highest tides are generally two or three days afterwards; the flow or rise of an average spring tide is about 21 feet at the harbour mouth, and 17 feet at the entrance to the Old dock; that of an average neap tide, 12 feet at the harbour mouth, and 9 feet opposite the Old dock entrance: but it may be observed, that the tides occasionally rise three to four feet higher, and sometimes, though rarely, a little more, and ebb sometimes two feet or more, lower than stated above. It may be proper to notice also, that when there are many vessels in the harbour, the ebb is not so low by nearly a foot, as when it is clear of shipping. The tide flows about five hours at the harbour mouth, and four hours and a half at the entrance of the Old dock.

THE OLD DOCK.

In consequence of the confined state of the old harbour and other inconveniences already briefly noticed, application had been made to government, a few years before obtaining the Act for making the Old dock, for a grant of part of the King's works near the Garrison, for the purpose of enlarging the harbour; but, as a legal quay formed no part of the scheme, it was opposed by the board of Customs, and nothing further was done. Some time after, however, it was intimated to the Collector and Comptroller of Customs at the port, that if a dock and legal quay were not made at Hull, the business would be removed to some other port connected with the Humber disposed to conform to these regulations; and a memorial was in consequence presented by the merchants of Gainsborough, praying that a legal quay might be established at that place.

It was now evident that something must be done to preserve the trade of the port, and it was at length resolved that the wishes of government as to a dock and legal quay should be complied with; but there appears to have

been great difficulty in obtaining an adequate subscription, and it was some time before this desirable object could be accomplished. The shareholders employed Mr. Grundy, the engineer, to furnish designs and an estimate for the work, which being approved of, and the necessary arrangements completed, application was made to parliament and an Act obtained in April, 1774, soon after which the work was begun.

At that period works of this kind were in their infancy, and we must not therefore look for the degree of perfection, either in design or execution, which has distinguished those of more recent times.

The Old dock, which appears to have been judiciously planned and laid out, is 1703 feet long, by 254 feet wide, so that the superficial content is nearly ten acres, and therefore capable of containing a hundred square rigged vessels; it was the largest dock in the kingdom at the time.

Dimensions of dock.

Excavation.

According to the sections the excavation averaged about 15 feet, the bottom of the dock being 15 inches above the bed of the old harbour opposite the entrance. The soil, which was altogether alluvial, was deposited upon land chiefly on the north side, and partly purchased for the purpose, which being raised thereby about five feet, and afterwards sold by the Dock Company, is now the site of several principal streets.

Dock walls. Plan, No. 2.

The walls are founded upon piling of a novel description, but very inadequate to the purpose: the piles, which are 12 inches wide by 9 inches thick at the top tapering regularly to 3 inches at the bottom, are driven under the walls and counterforts, longitudinal sleepers, 12 inches wide by 6 inches deep, trenailed on the pile heads, and 3 inch transverse planking laid and spiked down on them: the whole is of fir timber, and laid perfectly level.

The walls are wholly of bricks, many of them made upon the spot, coped with Bramley-fall stone, 12 inches thick, and 3 feet wide. They were built and grouted with mortar made of Warmsworth lime and sand, part of which was fresh water sand, and the rest selected from the excavation; the brickwork, for 14 inches in depth, is at right angles to the face, the rest of the wall horizontal,—a mode of laying by no means to be recommended, as the front is thereby completely separated from the other part of the wall, and the bond, a most essential part of all building, thus entirely destroyed.

In front of the wall, at intervals of ten feet, oak fenders 9 inches wide,

and projecting 7½ inches, are tenoned into three oak sills, 12 inches by 6 inches, built in the brickwork, and bolted and further secured to them by oak brackets spiked on each side.

From the insufficiency of the piling, and the foundation, which was only level with the bottom of the dock, not being low enough, the walls have subsided, and been forced forward in several places by the pressure of the earth behind; the greatest derangement is on the north side near the east end, noticed by Smeaton in his Reports as being at that time 2 feet 8½ inches out of a straight line in a length of 187 yards, and found by recent measurement to be now 3 feet 10 inches out in 202 yards, or about a foot more than when examined by Smeaton shortly before the opening of the dock: the wall on the south side nearly opposite the above, for 103 yards in length, is also forced forward about 20 inches in the worst place: the rest of the dock walls are nearly as straight as when first built. This wall has given way at different times, (probably from the quays being overloaded,) and in several places eleven or twelve feet at top have been taken down and rebuilt; piles have also been driven down in front of the wall, and a cap sill with transverse planking laid thereon, upon which the new wall has been erected; this has answered the purpose, and as a further security a mass of well rammed clay has been lately deposited at the foot of the weakest parts of the wall.

Lock and basin. The original lock was 200 feet in extreme length, and 36 feet 6 inches wide, by 24 feet 6 inches deep; there were six rows of grooved sheet piling 14 feet long across the lock, which was founded on 1245 bearing piles 12 feet long, of a similar description to those for the dock walls, and on these longitudinal and transverse beams were laid, and covered with 4 inch planking, so as to form a wooden floor, which was the customary mode of building at that time.

The lock walls were built with bricks, faced with Mexborough stone, from 10 inches to 3 feet, or, on an average, 18 inches deep in the bed, with occasional *through* stones to bind the work together; the hollow quoins and coping were of Bramley-fall stone, the faces of which were set in pozzuolana mortar, as also the front masonry: the gates were made of English oak, in an arched form, and but 12 inches thick, including the planking. There was only one clough or sluice, 3 feet by 18 inches, in each gate, which did not give sufficient power to cleanse the lock and basin, without having recourse to a small lighter and drag to loosen and remove the mud whilst scouring.

There was a common wooden drawbridge on the Dutch plan, over the end of the lock.

The basin to this dock was originally 212 feet long, and 80 feet wide, with brick walls like the dock, but the wall on the north side, from some defect in the foundation, gave way before it was finished, and was in consequence never raised to its full height, a sort of timber platform being erected on it, which remained till the basin was rebuilt in 1815.

The foundations of the lock walls were also insufficiently piled, as appears from Smeaton's Report, in which it is stated that "respecting the walls of the lock they have the appearance of being well built; we, however, observe some small sets therein which we impute to the want of strength in the foundation timbers." He further says, "that the floor of the chamber had risen about three inches in the middle, and that of the platform to the gates from two to four inches."

In the course of seven or eight years after the lock was built, the walls had yielded so much as to require to be taken down about 12 feet from the top: one side was rebuilt in 1785, and the other the following year.

Quays. The quays are spacious and paved with pebbles from Spurn Point. A legal quay extends on the south side of this dock from the river Hull to Whitefriar-Gate Lock, a length of 1558 feet, and contains an area of 18,160 square yards; the superficial content of the whole quayage being about 29,000 square yards.

Moorings. The mooring posts to this dock were originally of oak, 15 to 18 inches diameter at the top, 2 or 3 feet above the quay, and 8 or 9 feet in the ground, with two oak land ties, each 20 feet long, the ends of which were secured by cross timbers, and two piles to each: the posts are 12 feet from the side of the dock, and 14 or 15 yards asunder. A very high wind arising one night, soon after the dock was made, the ships moored in the evening on one side were found next morning on the other, having dragged several of the mooring posts along with them, a plain indication that these posts had not been very securely fixed. I understand that several of the posts were renewed about twenty years ago, but there are a great many of the original ones still standing, though the parts above ground are generally in a very dilapidated state, and much worn by the mooring ropes and chains. In taking up several of these we found them, excepting the sap and about an inch of the heart on the outside, very sound and good, to within two or three feet

of the ground; but the land ties, though also of oak, being within two or three feet of the surface, were generally a good deal decayed; some few which were of elm were completely rotten. In most cases the decayed wooden moorings have been replaced by stone ones, either of Peterhead granite, or a sort of free stone from near Rotherham, about 2 feet 6 inches above ground, 18 to 20 inches diameter at top, and 15 to 17 inches at the surface: by being thus tapered downwards, they have been so weakened, as to be occasionally broken off by the shipping in very windy weather. The part of the stone in the ground is about 2 feet square, and 6 to 8 feet long, set upon oak plank, and secured by land ties similar to the wood posts.

Sheds, warehouses, and cranes.

There are two sheds upon the legal quay 13 feet from the dock, 23 feet wide, and together 635 feet long, with doors at regular intervals on the south side, and small openings or shutters for the admission of light; the north side is quite open. The long shed was erected immediately after the opening of the dock; the other, several years later.

A little to the south of the sheds, on the extremity of the Company's land, stands a range of warehouses, 345 feet long, of irregular breadths, consisting of three floors besides the cellars, and comprising a space of about 2250 square yards. The cellars are all arched with brick, and there are six cranes to these warehouses, which being the only ones belonging to the Company, are now used indiscriminately for all the docks, a rail road being laid down nearly their whole length, for the conveyance of goods between the warehouses and the shipping in the different docks.

There are six wooden cranes to this dock, four on the south side, and two on the north; the latter are *well* cranes, very lofty, fixed about six feet from the side of the quay, and calculated to lift four or five tons: the others are of a lighter description, the jibs close to the dock, and supported by frame-work in the old-fashioned way; one of these is worked by a tread-wheel.

Mud in dock.

Various schemes had been suggested for cleansing the dock of the mud brought in by the tide; one was by making reservoirs in the fortifications or old town ditches, with the requisite sluices, by means of which the mud was to be scoured out at low water; another by cutting a canal to the Humber, from the west end of the dock, where sluices had been provided, and put down for the purpose, when it was proposed to divert the ebb tide from the river Hull along the dock, and through the sluices and canal into the Humber, and so produce a current sufficient, with a little manual assistance,

to carry away the mud. Both of these schemes were however abandoned, and the plan of a horse dredging machine adopted; this work began about four years after the Old dock was completed, and continued until after the opening of the Junction dock. The machine was contained in a square and flat bottomed vessel 61 feet 6 inches long, 22 feet 6 inches wide, and drawing 4 feet water: it at first had only eleven buckets, calculated to work in 14 feet water, in which state it remained till 1814, when two buckets were added so as to work in 17 feet water, and in 1827 a further addition of four buckets was made, giving seventeen altogether, which enabled it to work in the highest spring tides. The machine was attended by three men, and worked by two horses, which did it at first with ease, but since the addition of the last four buckets, the work has been exceedingly hard.

There were generally six mud boats employed in this dock before the Humber dock was made; since which there have been only four, containing, when fully laden, about 180 tons, and usually filled in about six or seven hours; they are then taken down the old harbour and discharged in the Humber at about a hundred fathoms beyond low water mark, after which they are brought back into the dock, sometimes in three or four hours, but generally more. The mud engine has been usually employed seven or eight months in the year, commencing work in April or May.

The quantity of mud raised prior to the opening of the Junction dock, varied from 12,000 to 29,000 tons, and averaged 19,000 tons per annum; except for a few years before the rebuilding of the Old lock, when, from the bad and leaky state of the gates, a greater supply of water was required for the dock, and the average yearly quantity was about 25,000 tons. As the Junction dock, and in part also the Humber dock, are now supplied from this source, a greater quantity of water flows through the Old dock, and the mud removed has of late been about 23,000 tons a year.

It may be observed, that the greatest quantity of mud is brought into the dock during spring tides, and particularly in dry seasons, when there is not much fresh water in the Hull; in neap tides, and during freshes in the river, very little mud comes in.

Town sewers. There are two sluices in this dock, for scouring the town sewers; both on the south side, one being opposite the end of Low-Gate, the other near the Whitefriar-Gate lock: they consist of a cast iron clough 3 feet 2 inches wide by 2 feet 11 inches high worked in a groove by means

of a screw, with a conduit, also of cast iron, 3 feet wide by 2 feet 6 inches high, the bottom being about 9 feet below the dock coping.

Dock opened.

By the Act of Parliament seven years were allowed for finishing this dock, but by great exertions the work was completed in four years, and the dock was opened on the 22d of September, 1778.

Rebuilding of lock and basin.

The next improvement in the order of time, was the Humber dock; but as an important part of the work connected with the Old dock, namely, the entrance lock and basin, has since been completely rebuilt on an improved plan, it may be advisable to give a brief description thereof before proceeding to the Humber dock.

State of old work.

This reconstruction became necessary in the early part of 1814, from the ruinous state in which the lock then was. The water being drawn out of the dock to within four or five feet of the bottom, a coffer dam formed at the outer end of the basin adjoining the harbour, and a temporary dam of clay three or four feet above the surface of the water, on the side next the dock, the lock and basin walls were taken down, and it was found that the stone facing was much decayed, the mortar almost entirely washed out of the joints, particularly above high water of neap tides, and the walls greatly defaced by the coal hooks and stowers used in passing vessels through the lock: below the level of neap tides the stone was in a better state of preservation, but from its softness was a little worn away by the shipping; the hollow quoins which had been forced forward were in a bad state, and caused a great quantity of water to be wasted. The piles, sleepers, and planking, in the bottom of the lock and foundations, were all perfectly sound; the nails and small spikes were much wasted, but a great many of the large spikes and bolts were so little corroded, that they were used again in the construction of the new lock; the foundations had however sunk, by which the upper part of the wall was brought forward, and the timbers of the floor were several inches higher in the middle than at the sides.

The gates, which, when new, were much too slight, had become actually dangerous, although there had been new head posts to them all: and when they were taken up, the mortices, tenons, and iron fastenings were so bad, that they literally dropped to pieces.

The basin walls and foundations were in much the same state as the lock; but the front piles were pressed down by the superincumbent weight, in some

places 18 inches lower than the back ones, and the top of the wall bulged out in consequence. The ground in this part appears to have been particularly soft.

New lock. The ground having been cleared, the rebuilding of the lock was begun in May, 1814, from the design and under the direction of the late Mr. Rennie, Mr. George Miller being the company's resident engineer. This lock is 120 feet 9 inches long within the gates, 24 feet 6 inches high above the pointing sills, and 38 feet wide at the top, being 18 inches wider than the original lock: the foundations and walls are nearly the same as in the Humber dock lock, which will be more particularly described hereafter; but it should be observed that all the old piles remained to strengthen the foundation. The inverted arch is built with bricks set in pozzuolana mortar, as also the side walls, which are faced with Bramley-fall stone, the first or lowest course being all headers 4 feet in the bed by 18 inches thick; the hollow quoins came from near Rotherham, and are set in the same mortar; the backing or body of the wall is brick work, with one entire *through* course and occasional *through* stones besides, set and grouted in common mortar; and the coping is of Bramley-fall stone, 4 feet wide by 15 inches thick, joined together with stone dowels. This lock appears substantial and well built.

Gates. The gates, except the planking which is $2\frac{1}{2}$ inch fir, are all of English oak, and are each 23 feet wide, 24 feet 3 inches high above the pointing sill, 16 inches thick at the heel, and $14\frac{1}{2}$ inches at the head, including the close planking: there are ten bars or ribs of a curved form, the versed sine of which is 12 inches in the inside, tenoned into the head and heel posts, and further secured by wrought iron straps and screw bolts in the usual way: the two gate sluices of cast iron are 2 feet 6 inches square in the clear, and are worked by a wrought iron screw and brass nut, with bevel gear at top. The gates are moved by machinery on the sides of the lock, turning a cast iron roller, round which the chain revolves; these chains are all of $\frac{7}{8}$ inch iron, and are fixed from 2 to 4 feet above the bottom sill for shutting, and 7 feet for opening the gates, the latter operation being assisted by a counterbalance weight to prevent the chains from running off the roller. There are one horizontal and two vertical rollers fixed in the front of the lock walls about ten feet above the sill, with another large horizontal one at the foot of each wall, round which the chains turn in working the gates. A cast iron socket in the bottom of the heel post $3\frac{1}{2}$ inches diameter by $1\frac{3}{4}$ inch deep, turns upon a cast iron pivot fixed on the platform; and

a friction roller of brass (by which the gate moves on a cast iron segment in the bottom) 10 inches diameter by 4 inches wide, is fixed in a cast iron box or frame near the meeting post, with a wrought iron regulating rod reaching up to near the top of the gate, for adjusting the roller to the proper height. The gate is secured at top by means of a cast iron anchor with wrought iron collar in the common way.

From the frequent working of the gates, the pivot and socket on which they turn at the bottom wear away, in which case the gates are occasionally lifted up a little by screws, and a piece of hard brass about an inch thick is nicely fitted into the socket, to restore the original height.

Balance bridge. The bridge over the lock is of cast iron, on the lifting principle, and 15 feet wide, the carriage way being 7 feet 6 inches, and the foot ways 3 feet 6 inches each; the whole length is 81 feet. The bridge consists of six ribs, $1\frac{1}{2}$ inch thick in the plain part, and 3 inches at the edge or flanch, 9 inches deep at the meeting or middle, increasing, though not regularly, towards the sides, and it turns on a cast iron shaft or main axis 8 inches square, with four round bearings working in plummer blocks, fixed in cast iron carriages, bolted to the masonry of the lock. When the bridge is to be opened, a cast iron flap, turning on an axis $4\frac{1}{2}$ inches square, is lifted by a lever, in order to give room for it to rise: this flap forms at the same time a guard or barrier against passengers, and after the bridge is lowered into its place it is let down and forms part of the roadway. The bridge is covered with 3 inch oak plank laid across and bolted to the ribs; in the carriage way the planks are, for preservation, overlaid with $1\frac{1}{2}$ inch fir or elm boards, which are renewed from time to time, and the foot paths are covered with similar boards on oak joists, elevated about 5 inches above the carriage way, with a cast iron curb on each side, and wrought iron stanchions and chains as a fence on the outside. In lowering the bridge, when first erected, one of the outside ribs was broken by striking against the under side of the fixed planking at the outer end; this was repaired by bolting a cast iron plate to one side, and for greater security all the ribs were afterwards strengthened in the same manner. It will be understood, from the principle of this bridge, that as it is raised, the outer end descends into a quadrantal pit or cavity, which, to ensure proper working, it is essential should be kept clear of water. The machinery is similar to that of the Junction dock bridges, which will be more particularly described afterwards; one man

can raise or lower each leaf in half a minute, but two men with the greatest ease.

From a small yielding of the walls, the bridge was forced from its bearings on both sides, by which the weight of the carriages passing over it was thrown upon the main shaft; this has lately been remedied by cramping wrought iron plates, $\frac{3}{4}$ inch thick, to the bearings of each rib. This bridge, the first of the kind erected in Hull, was cast and put up by Messrs. Ayden and Etwell, of the Shelf Iron Works near Bradford, and weighs, exclusive of the wood work, about eighty tons.

Basin. The entrance basin is 213 feet long by 80 feet 6 inches wide at the top, 71 feet at the bottom, and the same depth as the dock. The walls are of brick with a Bramley-fall stone coping, a *through* course 14 feet from the bottom, and oak fenders on the same plan as the Humber dock; the walls are supported at foot by means of brick inverted arches across the bottom 6 feet wide by 18 inches deep, with spaces ten feet wide between, and the whole is covered with earth to nearly the level of the lock sills.

Re-opened. This lock and basin were finished and re-opened on the 13th of November, 1815.

Lockage. With a rising tide, it is usual to begin locking when there is a depth of 6 to 7 feet on the sill, and when required, five pens can be made before the water is level inside and out; the gates are then all opened, and large ships passed at the top of the tide, after which they are again closed; but the penning is frequently resumed, until the water has fallen to about 7 feet on the sill, by which time five pens more have been made. Seven or eight hours a tide are thus occupied in locking; and when business presses, this is done during both tides. If there are many large vessels to pass, it is sometimes found necessary to draw off the water one or two feet, so that the surface on the two sides may become level sooner, and the gates continue longer open, of which advantage is also taken to pass craft without the labour and delay of lockage; but this practice is never resorted to, except in cases of necessity, as the deposit of mud in the dock is much increased by it, the water abstracted, which is comparatively pure from time having been allowed for subsidence, being replaced by the very muddy water of the tide. In busy times, the gates have also sometimes to be kept open for a short time after high

water, and in neap tides doing so is unobjectionable; but in springs it ought to be avoided, as from there being then a considerable current through the lock, when the tide has begun to ebb, there is some difficulty and risk in shutting them.

State of dock walls. Before concluding this brief account of the Old dock, it may not be deemed irrelevant to point out the state of the walls and foundations, as found in executing the Junction Dock, when they were taken down, at the western extremity, as far as the north gates of the Whitefriar-Gate Lock.

The timber and planking of the foundations were perfectly sound, and the spikes also generally in a good state; but the oak fenders were decayed and a good deal bruised and worn away at the upper part by the vessels; new tops had been scarved to many, but the part of the fenders below an average tide, say eight or nine feet under the coping, as well as the sills and brackets for securing them, were generally sound, the sap and a little of the outside excepted.

The front of the wall for about the same depth had but an indifferent appearance, the bricks being in places much decayed and rubbed away by the vessels, and the mortar washed out of the joints, but below this the bricks were generally in a much better state, and the pointing nearly entire. It has been before observed that the mortar for this wall was made partly from sand dug out of the dock, which was far from being of the best quality; the interior of the wall was grouted, and not very sparingly, as in some places the mortar was found nearly as thick as the bricks. The mortar in the inside of the wall varied very much in quality according to circumstances; where the wall was solid and undisturbed, it was very hard, requiring picks, and in many places sledges and wedges, to take it down; but where the wall had given way or been otherwise disturbed, and cracks and cavities thus caused in the inside, the mortar was in general very soft. This was observed in a variety of places, and it was not uncommon to see the mortar in one part of the wall exceedingly hard and good, and within a few inches from it, where the wall was open and the water had found its way, quite soft and bad, or but little harder than when first built. From this we see how essential it is, that building in water should have a substantial and immovable foundation, and that the walls should be completely solid and impervious, particularly where a good water lime cannot easily be obtained.

From the front of the wall not being properly bonded to the back, the parts are not only unconnected, but in many places entirely separate, so that a rod may be thrust down many feet between them. It was observed also, that where the wall had given way, it was completely separated from the counterforts, to the extent, I understand, of one to two feet or more in the worst places, whereby the strength of the wall has been greatly reduced.

THE HUMBER DOCK.

Before the Act was obtained for making the Humber dock, the Old dock and harbour were found insufficient for the shipping and increased business of the port. This want of accommodation had been felt and complained of for some time, and various plans and schemes were proposed for the improvement of the port, all having in view increased dock and quay room. One proposal was to make another dock on the east side of the old harbour, and connected therewith by a suitable lock: another was to convert the harbour itself into a floating dock, by an entrance lock near the Humber, and another lock near the north bridge; and to excavate a new channel for the river Hull from above the proposed dock, to the Humber, eastward of the Garrison: but fortunately for the port, neither of these plans was adopted.

The Dock Company, in order to obtain the best advice on a matter of so much importance, called in the able assistance of the late Mr. Rennie, who was afterwards joined with Mr. William Chapman of Newcastle-upon-Tyne, on behalf of the Corporation of Hull. These gentlemen furnished the plans for this dock, and the work was carried on and completed under their joint direction: Mr. John Harrop, an old servant of the company, (who had done the carpenter's work of the Old dock,) was the resident engineer, and was assisted by Mr. George Miller, afterwards his successor.

The Act of parliament was passed in 1802, and the work was begun early in the following year.

Area of dock. The area of this dock is seven acres and a half, and will contain seventy square rigged vessels, with ample room for moving them; but there have been a hundred sea-going vessels, besides thirty or forty smaller craft, in it at one time.

Coffer dam. The coffer dam at the south end of the lock, for keeping out the tidal water during the execution of the works, was 280 feet span, and the versed sine 140 feet; it consisted of two concentric rows of close Danzig piling, 13 to 14 inches square, and 7 feet 6 inches apart, well bolted and braced together, with a trunk and shuttle in the middle at the bottom, the internal space being filled up with bricks laid in sand to above the level of high water. This dam was firmly and judiciously constructed, but having sometimes a perpendicular head of water of nearly thirty feet against it, shewed signs of great weakness during an extraordinary high tide a little before the work was completed; being however promptly secured by shores and braces, no further damage ensued.

A steam-engine of six horse power was fixed upon the east side of the lock, and worked two 11 inch pumps, for keeping the works clear of water, and also at the same time, two 7 cwt. rams for driving the piles of the coffer dam.

Excavation. The excavation of the dock was 24 feet deep on an average, all in alluvial soil; the upper part for about five feet in depth was good clay, of which a great many bricks were made for the use of the works; and the rest of the soil was used to raise the ground and form the quay and road on the west side of the dock, and also the beach or shore of the Humber from the mouth of the old harbour to some distance above the dock; on part of this ground, several good streets have since been built. Notwithstanding the immediate contiguity of the dock to the Humber, a fine fresh water spring was found in the excavation of the lock pit, which was so powerful, that the stopping of it was attended with considerable difficulty and expense. The bottom of this dock, for reasons not very obvious, is not so low by ten inches as the lock sills.

The site of the basin, being outside the coffer dam, and overflowed by the Humber every tide, was excavated by tide work. Part of the soil was removed by horse runs, to raise the ground near the lock, and the remainder conveyed away in ballast lighters, and discharged in the Humber.

Dock-walls, Plan No. 3. The foundations are all piled, with a row of 6 inch grooved sheeting piles in front; the bearing piles are 9 inches, the counterfort piles 8 inches diameter. They were all driven with a ringing engine and a ram of nearly 4 cwt., worked by fifteen or sixteen men; these piles proved to be too short for so lofty a wall, where the ground in general is so soft and compressible. Longitudinal sleepers of half timber were bolted down

upon the heads of the bearing piles, the sheeting piles spiked to an inner waling of the same scantling, and the whole covered with 4 inch transverse close planking, on which the wall was raised. The timber used was Memel or Danzig, excepting the piles, which are chiefly of Norway fir.

The dock walls are all of brick, with the exception of a stone *through* course at the bottom of the fenders, three courses of stone on the level of an average tide, and the coping. The mortar was made of Warmsworth blue lime, and sharp fresh water sand only; the lime, having been ground in its dry state in a mill worked by a steam-engine, was mixed with two parts of sand, for the front work, and water having been added, the whole was ground again, and the mortar used immediately afterwards, whilst hot and fresh. The backing mortar was composed of one part of unslaked lime to three parts of sand, mixed and tempered in the usual way. The brickwork of the front and back was laid in mortar, the rest grouted every course; part of these walls being built a little before winter, the front mortar was affected by the frost, but the joints were afterwards raked out and pointed with pozzuolana mortar. The *through* course at the foot of the fenders is of Barnsley stone, 15 inches thick, those in which the fenders are fixed projecting a little from the face, and having a dove-tailed groove to receive each fender; the three courses above are also of Barnsley stone, the lowest being a *through* course: these stones are all properly squared and dressed and the front *bosted.* The coping is of Bramley-fall stone, 4 feet wide and 15 inches thick, squared and dressed, the front and top well bosted, the arris rounded off, and the joints secured by stone dowels.

Before the walls were raised to their full height, it was found that they had been forced forward on the east and west sides, near the middle, two feet from a straight line, carrying the foundation piling along with them. As a security, a quantity of earth, about ten feet high in the centre, diminishing gradually to six feet at each end, was immediately laid in front, where it still remains; a length of the upper part of each wall was also taken down and rebuilt in a straight line. Some time after the dock was finished, the water having been drawn down to within thirteen feet of the bottom, for the purpose of making a level bed for the counter balance weight of the gate chains, the east wall again gave way a little, but the movement ceased on the rising of the tide. The circumstance operated as a warning not to draw the water so low in future.

All round the dock, to protect the walls, there are oak fenders 12 inches square, let 4 inches into the brickwork, and projecting 8 inches before the face, dovetailed into stone corbels at foot, as before mentioned, and secured by oak ties with wrought iron fastenings near the top, which is covered with a cast iron cap. There are also two rows of horizontal fir fenders, 7 inches square, let into the upright ones by short tenons, with angle pieces to prevent vessels catching underneath or riding upon them, as the tide rises and falls.

Lock. The entrance lock is 158 feet long within the gates, 42 feet wide at the top, and 31 feet high above the pointing sills, on which the average depth is 26 feet at high water of spring, and 20 feet at that of neap tides.

The foundation consists of four rows of bearing piles, 16 to 19 feet long, for each wall of the chamber, and two rows for the counterforts; on the heads of these, longitudinal sleepers of half timber are bolted, transverse sleepers of the same scantling placed on edge securely fixed to them, and the whole is covered with 4 inch close planking, the interstices being filled in solid with brickwork, on which the inverted arch and side walls are built. There are five rows of 6 inch grooved sheeting piles, 16 to 20 feet long, driven across each platform, the bearing piles for which are 3 to 4 feet apart each way, and carry longitudinal sleepers, 12 inches square, with two courses of close transverse sleepers bolted thereon for 13 feet in length from the main sills, on which the pointing sills are fixed. The remainder of the platform is covered with 6 inch elm close planking, on which cast iron segments are laid for the gates to traverse upon. There is an apron or platform at the tail of this lock, about 50 feet in length, covered with 4 inch planking spiked to transverse sills, which are bolted down upon the heads of the bearing piles, with a row of 6 inch grooved sheeting piles at the outer end. The piles are of Norway timber, the sleepers and planking, except for the platforms, principally of Danzig fir, and the pointing and main sills of English oak.

The side walls are 6 feet 9 inches wide at top, and there are six counterforts on a side, each 6 feet square; besides the foundations for the bridge, which stand 9 feet higher than the rest. These walls and the invert are of brickwork, faced with Bramley-fall stone. The front was set in mortar composed of three parts of ground Warmsworth blue lime, two parts of ground pozzuolana, and five parts of sharp fresh water sand, properly mixed and screened, and well tempered; this work was done by men with beaters, till the erection of the mill, in which the mortar was afterwards ground wholly, and used immediately; the rest of

the work was set and grouted in common mortar, composed of one part of unslaked Warmsworth lime to three parts of sharp fresh water sand, mixed and screened, and tempered in the usual way. The hollow quoins are of Dundee stone, well squared and dressed, set in pozzuolana mortar, with close beds and joints, the parts in which the gates turn being well rubbed to a smooth surface, so as to be water-tight; this very hard durable stone, being of a fine grit, does but little injury to the heel posts, and is therefore very proper for hollow quoins. The south wing walls are also faced with Dundee stone for a short length. The coping is of Bramley-fall stone, 4 feet wide, by 15 inches thick, joggled together in the same manner as that of the dock walls.

Caisson. In the masonry at each end of the lock, there is a chase or groove 12 inches deep, 21 inches wide in the front, and 15 inches at the back, for receiving a caisson or floating gate, which was originally built as a preventer dam at the south end during the execution of the work, and was afterwards used to keep the tidal water out of the lock in repairing one of the gate chains; but having gone to decay, it has since been broken up. The keel was made to fit the stone groove so as to be water-tight, and about ten feet above the bottom, there was a cast iron cross cylinder, 2 feet diameter, communicating with the water on either side, by means of four apertures, 9 inches diameter, fitted with brass plugs worked by screws and rods, reaching to the deck, by which the water was admitted to sink the caisson in its place, and let out at low water when no longer wanted, so that, the plugs being inserted, the vessel rose by its own buoyancy the succeeding tide. This gate or vessel being very deep, and only 22 feet 6 inches in beam, was kept in a vertical position by about thirty tons of ballast.

Gates. The lock gates are all of English oak, except the planking, which is of fir; they are 31 feet 4 inches high above the pointing sills, and 25 feet 6 inches broad, measured in the curve line, the camber being $14\frac{3}{4}$ inches; the thickness is $16\frac{1}{2}$ inches at the heel, and $14\frac{1}{2}$ inches at the head, the 3 inch close planking included. Each gate originally consisted of twelve bars framed into the head and heel, and further secured by wrought iron straps and bolts; but a few years after they were put up, several of the lower bars being broken by the great pressure of the water and the heavy stroke of the sea in stormy weather, they were replaced by new ones, and several additional bars inserted, so that the gates are now a solid mass of timber (excepting the cloughs) for ten feet from the bottom. There are two cast iron sluices to every

gate, each 3 feet square in the clear, worked by a wrought iron screw, with a sluice rod reaching to the top. The machinery for opening and shutting consists of a 6 inch pinion, working into a cog-wheel 4 feet diameter, on the axis of which is a cast iron roller 2 feet 9 inches long by 10½ inches diameter, for the gate chain to wind on. The other parts of the gates and their appendages are so much like those of the Old dock lock, that it is deemed unnecessary to repeat the description.

Before the piers of the entrance basin were erected, the waves from the Humber sometimes forced open the outer gates a little, notwithstanding the great pressure of water behind; and the violent concussion in shutting fractured the lower bars, as already mentioned, and would in all probability soon have destroyed the gates had they remained much longer exposed. Since the erection of the piers the swell is much diminished; but even now, with strong gales from the south, it is dangerous to attempt to open or shut the gates by the machinery, and at such times recourse is had to blocks and tackle provided for the purpose. When the gates are left open after high water also, the current out of this lock, in particular, is so strong as to require great caution in shutting them; this used to be done at such times by what is termed *back handling*, that is, the gate-men standing at the machinery for opening, keep a tight hand upon it, to prevent the gates from closing too forcibly; but recently a safer and more simple plan has been adopted, namely, by a rope hooked to each gate head, and taking a turn round the mooring posts on each side of the lock, by which the gates can be eased to with the greatest safety.

Bridge. Over the centre of this lock there is a swivel bridge, 12 feet 3 inches wide; it is 81 feet 9 inches long, and composed of two parts, which, meeting in the middle, form a segment of a circle. The bridge consists of six cast iron ribs, about 2 inches thick in the plain part, and 2½ inches at the lower edge, connected together by cast iron braces, and planked with 2½ inch oak, which is protected by a covering of 1½ inch fir. The foot-paths, each 2 feet 8 inches wide, are slightly raised above the carriage way on oak joists, covered with fir boards, and have cast iron curbs next the road way; a wrought iron railing, 3 feet 7 inches high, runs along each side. On each side of the lock, in the stone coping of a large brick pier, there is firmly imbedded a cast iron circular plate, 11 feet 9 inches diameter by 6 inches wide, with a cross and pivot in the centre, also securely let into the masonry, and working in a socket underneath the

bridge, with twenty conical rollers, 6 inches wide, by $10\frac{3}{4}$ inches diameter at one end and $9\frac{3}{4}$ inches at the other, fitted in a frame, and revolving between the circular plate above mentioned and a similar plate in the under side of the bridge. The ends or meeting parts of the bridge are not described from the centre pivot or axis of motion, but from a point a little on one side thereof, whereby these parts, in shutting into a tongue and grooved joint, do not come into actual contact till the bridge is shut; it is then completely fast, being closely wedged to the abutments on each side and kept in place by two keys at the meeting, thus making the whole firm and secure. The machinery for opening and shutting the bridge, consists of two 8 inch bevel pinions, to one of which the handle is applied, and at the bottom of the vertical shaft of the other is fixed a 9 inch pinion, working into a spur wheel, 4 feet diameter, on the axis of which is another pinion, 12 inches diameter, which turns the bridge by means of a toothed segment at the outer end. One man can open or shut either part of the bridge with ease in half a minute. Messrs. Ayden and Etwell, already named in the account of the Old dock, constructed this bridge also.

Basin walls. The walls of the entrance basin are so much like those of the dock, that a very brief description may suffice. They are 10 feet wide at the bottom, by 6 feet at the top, fronted entirely with Bramley-fall stone, and having two *through* courses, and a stone coping, similar to the dock; the rest of the wall and counterforts is of brickwork; the front masonry, and also the back of the walls, are set in pozzuolana mortar, the remainder in common mortar, of the same proportions and mixed as for the lock. There are three rows of stout piling, 16 to 18 feet long, under the walls, and a row of 6 inch grooved sheeting piles, 16 feet long, in front, with transverse sleepers, and close planking over all; the counterforts are piled and planked in the same way. There was also a quantity of Hessle-cliff stone rammed between the foundation timbers, and about two feet in width behind the walls. This wall, on the outside of the cofferdam, was wholly executed in tide-work.

Quays. The quays are paved with spurn pebbles; the east side, and the south up to the lock, form a legal quay, upwards of 1000 feet long: the drainage is into the sewers by gratings every 25 yards.

Moorings. The mooring posts are about 10 yards apart, and 4 yards from the side of the dock; they are of wood, iron, and stone. The wooden ones are simply round oak trees, 18 inches in diameter at the top, driven

firmly into the ground by pile-engines, and having two shores, a little below the surface of the ground, abutting on the back of the wall, by which the strain of the shipping upon the posts is transferred to the wall; a plan that cannot be recommended. The iron posts (twelve pounder cannon) are 9 or 10 feet long, the breech or lower end being let into a stone block, and secured thereto by wrought iron straps and bolts, and also built round with brickwork up to near the surface of the ground. I understand that some of these posts are secured by land ties, but in general there is only a large stone laid to the back of the coping, thus throwing the strain upon the wall, as noticed above, in the case of the wooden moorings. The stone posts are of Peterhead granite and Dundee sand stone, of similar dimensions, and secured in like manner to those at the Old dock: but from their being too much tapered near the ground, several have been broken by the heavy strain in windy weather.

Dolphins. There are four dolphins in this dock, each consisting of five piles, the centre one perpendicular and standing above the others, which are battering, and the whole secured together by two tiers of cross braces, and planked over on top and sides, for 11 feet down. These dolphins were erected at the time the Junction dock was made, for the purpose of warping vessels in their passage to and from that dock, as well as for the more convenient mooring of ships on the west side of the Old dock.

Sheds and Cranes. A range of sheds, 750 feet long, 25 feet wide, and 15 feet from the side, extends along the legal quay on the east side of the dock: they are principally of fir timber, covered with weather boarding and enclosed with large doors on the east, but open on the west, except the bale shed at the south end, which is all enclosed, with large doors on each side. The roof is covered with blue slate, and the floor formed with 6 inch flags for a width of 15 feet, the rest being paved with spurn pebbles.

There are seven cast iron cranes to this dock, four on the east and three on the west side; the large one near the north west corner is a *well* crane, calculated to lift 10 tons; the vertical shaft is 5 feet 3 inches from the side of the dock, and its foot 15 feet below the coping; the jib is 19 feet 3 inches high to the under side of the pulley, and projects 22 feet. The other six cranes are all of the *pillar* kind, and calculated to lift 3 tons. The pillar is 6 feet high, and fixed at a distance of 5 feet from the dock, in a socket in the centre of a cast iron cross, securely bolted to the coping. The jib is 16

feet 6 inches high, projects 15 feet, and is movable on the pillar by a pivot and socket at the top, and a cast iron collar faced with brass at the bottom.

There are four wooden cranes to the basin, three of them well cranes calculated to lift 3 or 4 tons, and the other, which has been recently put up, a pillar crane for 2 tons; the jibs of all project about 20 feet, or 13 feet beyond the basin wall. These cranes are principally used for steam-packets.

Cleansing dock. This dock was not cleansed for three years and a half after it was opened, the dredging machine and mud boats not being completed until then; and such is the impurity of the water in the Humber, that during this time the mud had accumulated to the height of twelve feet at the south end of the dock, and three feet at the north, so that deeply laden vessels were prevented, at neap tides, from entering or going out.

Dredging machine. The dredging machine is worked by a steam-engine fixed on board a square flat bottomed vessel, 80 feet long, 20 feet wide, and drawing 5 feet water. The engine is 6 horse power, and works a 2 feet stroke forty strokes per minute, giving motion, by means of a bell crank, to four cog wheels, on the axis of the upper of which is a square tumbler, with one corresponding at the lower end of the bucket frame. Round these the wrought iron buckets, twenty-nine in number, revolve by an endless chain, and the mud is discharged over the upper tumbler into a spout leading into lighters lying alongside; the ladder turns on an axis at the upper end, and the lower end is raised or lowered through an opening in the middle of the boat, by a crab and tackling fixed directly over it, by which the buckets are adapted to the proper level for taking up the mud. The vessel is drawn to its work by means of a cable revolving round a roller attached to the engine, and from it by two men at a crab in the stern; there is also a contrivance for moving it sidewise when required. It is usual in inland navigations and canals, where the dredging machine has to pass through locks and bridges, to have the buckets in the middle of the vessel, as in the present instance; but in docks, harbours, &c., where there is no want of room, they are much better on the outside, as there is less waste in discharging the mud into the lighters, and there may be a double set of buckets, one on each side, if necessary.

Four men, including the engine-keeper, are required to work this machine, and two more to attend the lighters. The work has for a short time been upwards of 2 tons per minute, (or twelve buckets of 4 cwt. each,) and where the mud is in plenty and there is no impediment, 60 tons per hour may easily

be raised; but the ordinary work is about 45 tons an hour, or twelve boats containing from 500 to 550 tons per day of twelve to fifteen hours.

Mud boats. Plan, No. 4. The mud boats are flat bottomed and sharp at each end, and draw, when fully laden, about 4 feet water. Six of them, which were formerly used exclusively for the Old dock, are 48 feet long at top, 17 feet 6 inches wide in midships, by 5 feet 6 inches deep, and carry 40 tons on an average; the six Humber dock boats are rather larger, carring 48 tons each. They are ceiled inside in a sloping direction like a hopper, with two trap doors in the bottom, through which the mud is discharged, the water rising in the boat to the same level as on the outside, but the cavity between the ceiling and the bottom preserving the buoyancy.

When laden, these boats are linked together in pairs, six usually forming a set, which require ten or twelve men to work them; they generally go out of dock when the gates are all opened, a little before high water, and are warped 100 or 150 fathoms from the pier-head, where the mud is discharged; the empty boats then return to the dock, the time occupied being usually from two to three hours, according to the rapidity of the tide, and as the passage is more or less clear of shipping.

Quantity of mud. The quantity of mud taken out of this dock, was about 36,000 tons a year before the Junction dock was made; since then it has been about 30,000 tons, the diminution arising from the water being now in part supplied from the river Hull, which is much purer than the Humber *, and having also to flow through the Old and Junction docks, where a great part of the mud is deposited.

Scouring of basin. The tide-basin being connected with a river highly charged with mud, it was necessary to make provision for cleansing it. The head, or north end of the basin, is partly scoured by water from the lock, conveyed 130 feet in two cast iron pipes laid close behind the wall, and 4 feet diameter next the lock, diminishing to 2 feet 6 inches at the outer end; these pipes are in 9 feet lengths, each 30 to 35 cwt., with flanches at the ends bolted together, and resting on a cap-sill, supported by two piles at each joint. To these mains, at equal distances, are connected ten 18 inch pipes on each side of the lock, which discharge themselves through the basin wall, about 5 feet

* The respective quantities of deposit of the two rivers are found, by experience, to be nearly as one to three.

above the level of the sills, on a wooden apron 40 feet wide, laid in front to prevent the foundations from being undermined. Two other mains, also 4 feet diameter, are connected with the dock, one at the south east, the other at the south-west corner, terminating at the south-east and south-west corners of the basin respectively; their bottom being about two feet above the level of the lock sills, and aprons placed at the ends, similar to those at the head of the basin. These pipes were intended to scour away the mud along the inner sides of the piers, and also to assist in preserving a deep channel between the heads. There is a vertical cylinder, 4 feet 6 inches diameter, to each of the latter pipes, near the corner of the dock, with a cast iron sluice at bottom for opening and shutting; the sluices for the scouring pipes at the head of the basin are in the face of the lock wall, in the gate recesses; they are all worked by wrought iron screws with handles at the upper end of the sluice-rod. Several of the pipes from the dock to the basin, from being too slight, failed before the dock was opened, and were replaced, at great labour and expense, by new ones; others, which were less fractured, were repaired and strengthened by ribs in the inside.

To shew the effect of these sluices, I would state that the four from the lock, and the small ones at the head of the basin only, when all open, lower the water in the Humber dock a foot in four minutes: the latter, with the two from the dock, are generally worked at low water, twice every spring-tide, and notwithstanding their great power, only scour out a narrow channel at each place, sufficient for the steam-packets and small craft to lie in; but being assisted by the sluices of the gates, the main channel from the lock into the Humber is effectually scoured, and maintained to nearly the depth of the sills. Over the rest of the basin the sluicing has no power whatever, and the mud deposited there has been removed by manual labour, at great expense; two mud lighters having been, till within the last two years, almost constantly employed upon it since the dock was opened.

It having occurred to the writer of this, that the water wasted in locking might be beneficially used in cleansing the basin, he recommended a new scouring pipe to be laid at the north east corner, on a much higher level than the other pipes for the purpose. A new 4 feet pipe was accordingly put down in the spring of 1831; from its junction with the old pipe to the outlet in front of the basin wall is 18 feet, and the bottom at the outer end is 10 feet 6 inches above the lock sill. There is a sluice, worked by a rack and pinion, at the

top of a brick shaft or well, to stop the old pipe and divert the water through the new one, when in use; at other times, this sluice being drawn up, the water is discharged as before. At the outer end of the new pipe is a wooden spout, 18 feet long, turning on hinges in the wall, so as to be reared up against it when not in use, and to the end of this another spout, 85 feet long, is connected, which can be turned so as to scour in almost any direction. It should be observed, that the largest quantity of mud is deposited on this side of the basin, and that, before the making of this sluice, it had accumulated to a great height, and become so exceedingly hard and tenacious, that it was found necessary to remove it into the stream by workmen with spaddles. In this manner about 12,000 tons of mud were removed in eight weeks after the sluice was set to work. Since that time there has been only one man to attend the sluice about three or four days every spring tide, except when clearing away the mud alongside the east wall and near the east pier, which cannot be done by the scouring power alone. The new sluice, when in full operation, lowers the water in the three docks about 6 inches an hour, and usually runs about three or four hours each tide.

Sewers. The sewers are all of brick, and are 3 feet wide by 4 feet high; that on the east side commences at the end of Myton-gate, at a depth of 8 feet 6 inches below the dock coping, and terminates at the north end of the basin 4 feet lower, the extremity being closed by a flap, opening outwards, to discharge the drainage water and shut out the tide. This sewer was formerly cleansed by manual labour, but is now scoured by a sluice constructed for the purpose on the east side of the Junction dock. The sewer on the west side discharges itself into one in Kingston street, which leads to the general outfall into the Humber, at Limekiln Creek.

There is an iron sluice at the north-east corner of the dock, 7 feet 6 inches below the coping, protected by a wooden door, worked by a screw, and having an iron conduit, 2 feet 6 inches wide by 2 feet high, leading from it to scour the town sewers.

Dock opened. The water was let in on the 3d of December, 1808, and the dock publicly opened for business, with due honours, on the 30th of June, 1809. The expense was defrayed by the Dock Company, and the Corporation and Trinity House jointly, the two latter contributing one moiety of the expense, and the Company the other, for which purpose sixty new shares were created, under the authority of an Act of Parliament.

Pier heads. Plans, Nos. 5, 6, and 7.

The piers of the entrance basin were begun soon after the dock was opened: their construction will be better understood from the drawings than by description. They are wholly of fir, of the scantlings stated on the plan No. 7, and the filling up or hearting is of Hessle-cliff stone; the sheet piling on both sides was grooved. The passage between the heads is 105 feet at the top.

Slip-way.

In the summer of 1829, a slip, for repairing the mud boats and the lock gates, was built on the west side of the entrance basin, abutting upon the Humber. The length is 66 feet, the width 28 feet 6 inches, and the depth 11 feet at the lower end, diminishing upwards in the proportion of six horizontal to one vertical; the side walls are of brickwork, with stone coping; the bottom floor is covered with 3 inch fir plank, spiked to transverse sleepers, supported upon piles. The coping and front brickwork were set with Parker's cement and sharp fresh water sand, in equal proportions, and although exposed to the waves and swell of the Humber, have stood hitherto with scarcely a failing joint.

Lockage.

What has been said on this head respecting the Old dock, applies also in a great measure here. Locking is begun when there is about the same depth of water, but the sill being 6 feet lower than in that dock, the work can be carried on longer, and fourteen or fifteen pens made at one time. As many as 25 sea-going vessels have passed this lock in a tide, thirteen of the largest when the gates were open for about an hour at high water, and the rest by penning.

There are usually three men to open or shut each gate, which they do in two minutes to two minutes and a half; but frequently two men do the work. With 6 or 7 feet of water on the sill, in average tides, the lock can be emptied or filled in about eight minutes, with all the sluices; but this is seldom done, no more than two sluices being generally opened, for fear of damage to the shipping or the works from the great agitation of the water: with two sluices, the time is about 14 minutes. It may be observed, that two men can easily raise or lower one of these sluices, with a full head of water, in five minutes.

State of walls.

In concluding this account of the Humber dock, I would, as before, briefly advert to the state of the walls and foundations, as found when taken down in executing the Junction dock.

The timber in the foundations, which was all fir, was, with the exception of the sap, invariably as sound and good as when first put down; the oak fenders, constantly under water, were also in a good state, but the upper part of many of them beginning to decay, and a few actually rotten; as were the horizontal fir fenders, and the oak ties near the top of the wall. The wrought iron varied considerably: in some places the spikes in the foundations were quite fresh and good, in others a little corroded, and in others almost rusted away.

The mortar was generally very soft, but at the wide parts, and especially the foundations of the old communication at Myton gate, so much so, that it might have been beat up without a drop of water, and used again. In the parts near the top of the wall not so much exposed to damps, the mortar was tolerably hard; but I saw none, except in the inverted arch of Myton-gate old communication, that would bear any comparison with that of the Old dock; the mortar in that invert, which was made from ground lime, mixed with a proper proportion of sand, and then ground again in the mill, was, however, so hard, and adhered so firmly to the bricks, that it required a sledge and wedges to separate them. The mortar in the front of the wall had much the same appearance as that of the Old dock, being soft and very much out of the joints for nine or ten feet from the top; below this the joints were not wasted, but had thrown out a sort of stalactite or calcareous incrustation that entirely covered the face of the wall. Notwithstanding the soft state of the mortar in these walls, I am of opinion, from their being in general so well flushed or grouted as to be impervious to water, that it will ultimately acquire considerable hardness, although perhaps not for many years. This I infer from the state of the mortar in the Old dock and several other walls that I have had an opportunity of observing, built with nearly the same kind of lime.

The pozzuolana mortar, where always wet, or where wet and dry alternately, and also where constantly dry, was found in general exceedingly hard, being both in hardness and colour very much like a well burnt red brick. This mortar usually adheres very well to the bricks, but sometimes not so well to the stone, partly perhaps from the stone being set too dry, which is commonly the case in summer, and partly from a property peculiar to mortar made from magnesian stone, of expelling or throwing the lime to the outside, either in a dry state, like *flour*, or where the walls are wet or damp, like

paste; but whether arising from these causes or not, this want of adhesion detracts very much from its other excellent qualities as a valuable mortar for aquatic buildings.

The stone was found in a very good state, particularly the Dundee and Bramley-fall; the Barnsley stone, a little above and below high water, was in places somewhat wasted and decayed, but in all other parts sound and good.

Repair of lock gates. The gates and hollow quoins of the entrance lock, having lately undergone some alterations and repairs, it may be proper in this place to notice their state and mode of reparation.

From a defect not uncommon in artificial foundations, the lock walls had subsided a little, and come over about three inches on each side at the top, thereby contracting the lock six inches, which caused the gates to open and shut badly; one of the gates in particular required four men to work it.

Mr. Walker, who was then engaged in the construction of the Junction dock, was called to advise on the subject, and recommended that these gates should be taken up, the hollow quoins brought to a vertical line, and afterwards secured by land ties. The gates were accordingly lifted in the spring of 1830, by means of two powerful crabs, and two sets of stout treble blocks and pulleys, with a 5 inch fall, one pair being applied at the head, the other at the heel of the gate, and the whole suspended from the butt ends of two large oak trees, raised five feet above the coping, with the inner end resting on the ground, and kept down by two large stones, near four tons each; the chains to which the lower blocks were lashed, were fastened round the sixth bar from the top, blocking being placed between each bar upwards, the better to sustain the weight of the gate. Being thus prepared, the gate, weighing thirty tons, was lifted about eight feet, by a set of men at each crab, when, to take the strain off the blocks and tackling, a chain being passed several times round the gate-bar and the tree on the wall, the blocks were eased till the chains bore the principal part of the weight.

The hollow quoins were then dressed to a true perpendicular, and afterwards firmly secured by land ties, nearly similar to those of the Junction dock, which will be hereafter more particularly described. The quoins of the north gates could not be dressed down, on account of the water in the dock, but were securely land-tied in the same manner as the others.

The timber in the gates was all sound; but the bottom bar, from the great pressure against the sill, was worn away upwards of an inch in depth, and the heads and heels were also rubbed a little; the hoops at the foot of the meeting-posts were cut away an inch or more by dragging upon the traverse rails. The wrought iron straps and bolts were much corroded, and came off by a tap with a hammer in thick flakes; the cast iron sluices and frames were particularly soft for about an eighth of an inch on the outside, and might be cut with a knife, like lead; the cast iron plates of the pointing sills were very rough, or in holes and furrows, as if eaten away.

After the repairs were all completed, the gates were lowered into their places. The time occupied in performing the whole was about eight weeks, during which there was very little interruption to the shipping.

THE JUNCTION DOCK.

It appears that a short time after the Humber dock was made, so desirable was a junction of the two docks considered, that a temporary canal was proposed to effect it; this would no doubt have been of great service, as at that time dock room was not so much wanted as a safe and expeditious passage between the docks, which such a canal would have given. This scheme, as well as the more effectual one of a new junction dock, was, however, from one cause or other, deferred till further delay would have been highly injurious to the commerce and trade of the town as well as to the interests of the Dock Company.

By a clause in the Humber Dock Act, the Company were required to make a third dock whenever the shipping frequenting the port attained a certain amount of tonnage therein specified, provided a moiety of the expense was furnished them for the purpose. Some difficulties having, however, taken place in raising the stipulated supplies, the Company, impressed with the urgent necessity of making another dock, resolved, much to their honour, to execute it solely at their own expense, and the necessary arrangements having been completed, the work was begun in October, 1826, according to the designs and under the direction of Mr. James Walker, Civil Engineer, assisted by Mr. Thomas Thornton, the then resident engineer of the Company, as superin-

tendent of the works, in which office he was succeeded, in the month of July following, by the writer of this account.

It is proper in this place to state, that in the early part of the year 1826, Mr. Telford was employed by the Exchequer Bill Loan Commissioners to survey and report upon the proposed works; and the Dock Company being desirous of having the best advice, availed themselves of the opportunity of taking the opinion of that distinguished engineer. His report in general confirmed the plans of Mr. Walker; the principal alteration recommended was the substituting of a lock at each end of the dock, for an entrance with tidal gates only, and it was adopted.

Area. This dock is six acres in area, and is capable of containing sixty square-rigged vessels, with room for passing to and from the other docks.

Temporary works. The first preparatory works were the two coffer-dams, which were constructed principally of Memel timber; the south dam, or that next the Humber dock, was the largest, being 220 feet span, with a versed sine of 61 feet. The space between the two concentric rows of close piling, which were 6 feet apart in the clear, was filled to the level of the dock coping with clay puddle, the mud in the bottom having been previously well cleansed out; these piles were about 40 feet long, and 13 to 14 inches square. The gauge piles in front, forty-two in number on each side, were about the same dimensions, and had two rows of wale pieces, 13 by 8 inches, between them and the close piling on each side of the dam, all properly framed and bolted together. The close piling was connected together by an inner wale and cross braces near the top, and wrought iron tie rods lower down, and was further strengthened by a mass of loamy earth and loose bricks thrown in at foot.

On the concave side of this dam, and connected with it, was the temporary bridge. The road way, 24 feet wide, was supported by three rows of whole timber piles, braced together, and connected with the coffer-dam; and on their heads were transverse cap sills, carrying the bearing joists, which were covered with 3 inch planking and paved; a close boarded fence, six or seven feet high, was fixed on each side. From the great height of the dam, and there being at times a pressure of 28 feet of water against it, some of the piles were a little bent, and in very high tides the water found its way through rather freely near the top, particularly along the upper cross braces, but attention

being given in time, no detriment to the works ensued. It was found in the repairs, that the puddle had settled from 6 inches to a foot below the cross braces, and that this was the principal cause of the leakage, as the earth for the puddle was good, and the work appeared well done.

In order to guard against accidents, a preventer dam was afterwards made across the centre of Myton-gate lock, in the form of a segment of a circle, the convex side being next the Humber dock. This dam was chiefly composed of tenacious earth well rammed, with a dry brick wall on each side, 6 feet thick at bottom, diminishing to 2 feet 6 inches at top, and including the walls, was 30 feet wide at the bottom, and 8 feet at the top; it was carried to the height of the coping of the lock.

The gates also to both locks, after being hung in their places and finished, were well shored and braced, which turned out afterwards to be of the most essential service.

The north coffer-dam, at the west end of the Old dock, was 115 feet span, and the versed sine 14 feet. The plan of this dam and temporary bridge, and the scantlings of the timber, were similar to those of the other dam, except the piles, which were five feet shorter, the depth not being so great as in the Humber dock. This dam stood remarkably well, though there was sometimes a small leakage during very high tides near the walls and upper part.

There were two cast iron pipes laid along this dam for supplying the town with water while the works were in progress.

Two steam engines, six horse power each, were used for clearing the works of water; that at the south end of the dock was erected about the same time as the coffer-dams, and was also occasionally employed for grinding the pozzuolana; the other was put up in the end of 1827, at the east end of St. John's church, and was principally employed in pumping the water out of the Whitefriar-gate lock and the north end of the dock; it was also sometimes used for pugging mortar. This engine was taken down some time before the works were completed; the other remained until they were finished, a nine-inch pipe for conveying away the water having previously been laid through the west wall of the dock, and securely plugged after the engine had done working.

Water in the works. The water that arose in the excavation was not considerable; it was nearly pure, its slightly saline taste being caused, it is imagined, by its passing through the alluvial soil, which no doubt had been formerly deposited by the tide.

Excavation. The excavation of the dock and lock pits commenced soon after the coffer dams; the principal part of the material, over and above what was necessary for backing the walls and forming the quays and roads to the bridges, was used to raise the adjoining low ground and as ballast for shipping. The sides of the dock were cut to a slope of about one horizontal to one vertical, and the lock pits about one and a half horizontal to one vertical, and formed in steps, 3 feet wide, to receive the backing. The top, for 4 or 5 feet below the surface, was a stiffish clay, of which a great many bricks were made for the use of the works; below this, to the bottom of the dock, was silt, or a mixture of mud and sand, evidently left by the tide, from the small shells and other extraneous matter interspersed in it; this soil becomes exceedingly firm and solid very soon after removal. Several slips occurred both in the dock and lock pits; one on the east side of the dock, near the south end, (probably caused by the old fortifications or town ditches,) was about 90 yards long, and extended back to the buildings, several of which gave way, and had to be rebuilt; some of the foundation piles near the south-east corner of the dock were also forced forward. The ground was a good deal cracked in other places on this side, but further damage was prevented by shoring with timber; and the smaller slips that took place, particularly in the lock pits, were attended with no further inconvenience than the expense of their removal. The average depth of the excavation of the dock was 19 feet, that of the lock pits 6 to 7 feet more; the quantity of excavation was about 300,000 cubic yards.

Piling of foundations. The bearing piles were chiefly of American red pine, 10 inches square; the sheeting piles of Memel fir, 6 inches thick, with tongue and groove 2 inches square; all were driven without shoes, but the heads were in general hooped, to prevent splitting. The piling commenced in the dock wall on the east side, the first pile being driven near the south-east corner.

Pile driving. In all buildings resting on piling, it is important that the piles should be well driven, so as to carry the weight of the superstructure, and also to resist the lateral pressure, which in dock walls like the present is very considerable, and in alluvial soils of a loose and yielding nature, more than ordinary strength is necessary in this direction. Such being the case, and having before him the example of the other two docks, the walls of which had both given way, Mr. Walker was particularly desirous that the piling of the Junction dock should be effectually done; and for this end, requested to have an account of the driving from time to time, and where the ground proved softer than

ordinary, longer piles were used: indeed, the length and size of the piles were adapted as much as possible to the nature of the soil, varying in length from 10 to 18 feet in the dock walls, and in the locks some of them were 24 feet long.

Much irregularity prevails in pile-driving; sometimes a pile will go down at the last stroke more than it did at the third or fourth, though the fall of the ram and the density of the ground may be nearly the same, and the friction of course greater. Hence we perceive how uncertain all theories must be which profess to ascertain the actual weight a pile will bear, by having given the weight of the ram, the fall, and the depth driven at a stroke. There can be no doubt that a great deal depends upon the state of the head and point, for when these are sound and perfect, the pile will penetrate much deeper by a given stroke, than when soft and bruised; this is well known to pile-drivers, for frequently, when the pile moves but little or none, by sawing or even paring off a little of the head, it will go down again freely: also, if the weight falls exactly in the direction of the pile, and strikes the head fairly, so that the two bodies come into actual contact in every part, the pile will go further at a blow than when the stroke is oblique and the head only partially struck by the ram.

The sheeting piles under the front of the dock walls, driven by a crab engine, with a $10\frac{1}{2}$ cwt. iron ram, the fall varying from 8 to 18 feet, or 12 feet on an average, went down, at the end, about an inch at a stroke; the bearing piles, with a 20 feet average fall, about $1\frac{3}{8}$ inch, except in particularly hard ground, where they did not go down more than half the above at a stroke. The piles of the dock walls all battered about $2\frac{1}{2}$ inches to a foot.

The bearing piles in the foundations of the locks were driven with a ram of $13\frac{1}{2}$ cwt., and the average depth per stroke, when fully driven, was about 2 inches, with a 24 feet fall. The sheet piles, driven with a ram weighing $11\frac{1}{2}$ cwt., went down $1\frac{1}{2}$ inch with a 17 feet average stroke.

There is greater regularity in the driving of piles by the *ringing* than the *crab* engine, which is attributed principally to the head and point being much less injured, in consequence of the shorter fall of the ram, and its being of wood; but as the crab has the advantage in point of economy of working, the ringing engine was but little used, and that only for the dock piling. The bearing piles driven by it went down, on an average, $1\frac{1}{2}$ inch in thirty strokes, with a six feet fall, when fully driven; and the sheeting piles, 1 to $1\frac{1}{2}$ inch

with the same fall and number of strokes. The points of all the bearing piles were very obtuse, tapering not more than 12 inches, the better to support the weight of the walls.

It is well known that in piling, the ground, particularly if soft, becomes much consolidated, the first piles driving more easily than those after; on this account it was found advisable to drive the sheeting piles first, as they then went easier and were truer than when driven after the bearing piles; and this was more particularly the case in the lock pits, in some parts of which, especially under the platforms, where a great number of piles are inserted in a small space, the ground with the piles, after they were driven, rose together several inches.

Under the dock walls there are 2,411 bearing piles, containing 18,500 cubic feet of timber, and 2,140 lineal feet of sheet piling, 12 feet long, containing 12,840 cubic feet. In the Myton-gate lock there are 923 bearing piles, containing 10,126 cubic feet, and 540 lineal feet of sheeting piles, 16 feet long, (except the row next the Humber dock, which is 20 feet long,) containing together 4,440 cubic feet. In the Whitefriar-gate lock there are 956 bearing piles, containing 9,862 cubic feet, and 600 lineal feet of sheeting piles, 14 feet 6 inches long, amounting to 4,350 cubic feet.

It may be useful to know the actual weight sustained by some of these piles. The bridges are each supported by about twenty-eight 16 feet piles, and the superincumbent mass of masonry and iron being about 600 tons, there is a load of upwards of 20 tons on each pile; this is borne without settlement.

In variable ground it is not to be expected that all the piles can be equally well driven; but it may be stated, that the only yielding observed in the whole of this work, was at the projecting corners of the locks adjoining the dock wall, where a small crack, about the thickness of a knife blade, or little more, appeared for a few courses below the coping, caused, as it is believed, not by the sinking of the piles, but by the lateral pressure of the earth behind, on a part which from its construction is necessarily weak.

Dock walls. Plan, No. 8.

We proceed now to the dock walls, in the foundations of which an arrangement of the piling somewhat different from that in previous use was adopted. A row of bearing piles having been driven outside, a wale, 12 by 6 inches, was bolted to it, and the sheet piling driven behind and spiked to this wale. The back piles having also been driven, transverse sleepers of half timber are fixed on the pile heads, and over them were laid three

longitudinal planks, 12 by 4 inches. Except the main piles, the whole is of Memel timber, and well spiked together.

The space for 18 inches below the sleepers is filled up with brick rubbish, or Hessle-cliff stone, puddled in with hot lime and sand, and a similar concrete is laid at the foot of the wall, and covered with earth as an additional protection to the foundation.

The wall is of brickwork, faced in part with stone, and built in mortar consisting, for the backing, of one part of unslaked blue Warmsworth or Weldon lime to three parts and a half of sharp, clean, fresh water sand, and, for the front, two parts and a half of sand; but a great part of the outside, or facing, was set in the mortar hereafter described for the stonework.

The stone facing, which extends for a height of 11 feet 9 inches from the top of the wall, is of Bramley-fall stone, in 12 inch courses, except the lowest two courses, which are of Barnsley and Whitby stone, 15 inches thick; the coping is also 15 inches thick. The work is laid with one header to two stretchers, the headers being 1 foot 9 inches to 2 feet 3 inches on face, by 2 feet 9 inches to 3 feet 3 inches in bed, and the stretchers 2 feet 6 inches to 3 feet 6 inches long by 18 inches in bed, except at the corners of the dock, where they are 2 feet deep. The joints are champhered in front, the four lower courses are hammer dressed on face, and the rest neatly *bosted*. The coping, which is 4 feet wide, is secured by a 4 inch square dowel at each joint.

All the masonry, except the hollow quoins, is set in mortar, composed of two parts of unslaked blue Warmsworth or Weldon lime, one part of finely ground pozzuolana, and four parts of clean, sharp, fresh water sand, tempered in a pug-mill; the mortar for the hollow quoins was composed of one part of lime from Haling, near Rochester, one part of ground pozzuolana, and two parts of sand. The whole of the mortar and grout was used in the hot or caustic state.

The walls, except near the church, are curved horizontally, (7 feet on the east and west sides,) a mode of construction which, giving great additional strength, is advantageous in all situations, but more particularly in soils like those of the Hull docks.

Locks. Plans, Nos. 9 and 10.

The locks are 120 feet long within the gates, 36 feet 6 inches wide at top, and 25 feet high above the pointing sills; the construction of the two being, with some trivial exceptions, alike, a description of one will suffice: we take the first begun, viz. that at Myton-gate.

The construction of the timber work of the foundations, is believed to be

in some degree new, and appears to connect the different portions together more effectually than the ordinary mode. The piling is in rows driven at the intervals shewn by the sections, with additional piles under the hollow quoins and traverse rails, the better to support the weight of the gates. Longitudinal sleepers of whole timber are laid upon the pile heads, and over them transverse sills, 12 by 6 inches, and a foot apart in the chamber, and 12 inches die square, close together, with water-tight joints, in the platform; in laying the sills of the platform, the last, which was about the middle, was made tapering, and driven down by a pile engine, whereby the joints were wedged up. These sills and sleepers are all of Memel timber, but could elm of the requisite lengths and scantlings have been procured in sufficient quantities, it would have been preferable, as spikes hold much better in it, and drive without splitting the timber. The platforms are covered with 6 inch elm planking, laid upon a bed of tarred felt, firmly spiked with close water-tight joints. The platforms of the reversed gates were done nearly in the same manner, but without felt, and the transverse sills are laid about nine inches apart, the interstices being filled up with brickwork. For economy, the foundations of the bridges were not laid so low as the rest of the lock, but particular care was bestowed on the driving of the piles, which are 22 feet long, by 11 inches square. The sills generally are spiked down, but in the platforms they are secured by two *dogs* to each pile.

The pointing sills were not fixed till the lock was nearly completed. The principal ones are of African oak, 18 inches die square; they were sunk $1\frac{1}{2}$ inch into the planking of the platform, strengthened by oak cleats abutting on the back sill, and the whole secured by jagged bolts, straps, &c. A cast iron plate, about 12 feet long by 5 inches wide, was secured to the top of each sill near the middle of the lock, to prevent injury from deeply laden vessels, and as a further security, there is a strong sill at each end of the lock, laid level with the pointing sills. The reversed pointing sills are 14 inches square, and are secured nearly in the same manner as the principal ones.

The ground was taken out to a foot below the heads of the piles, and the space filled with Hessle-cliff stone, flushed with soft mortar up to the top of the longitudinal sleepers; the intervals between the transverse sills are made up with bricks as a flooring for the inverted arch, which in the chamber of the lock is entirely of brickwork, except the stone quoins at the ends. The invert

consists of three separate rings of headers set in pozzuolana mortar, the work behind being laid in level courses with common mortar and well grouted: the short inverted arches between the direct and reversed hollow quoins, are chiefly of Mexborough stone, bosted on face and radiated in the joints; the facing over them is likewise of stone, as also that of the wings beyond. The work of the side walls of the lock is generally of the same character as of those of the dock, except that the stones of the facing are of somewhat larger dimensions and greater depth of bed.

The hollow quoins are of Dundee stone, 5 feet 6 inches long by 3 feet 6 inches wide, and in 12 inch courses to correspond with the ashlar facing, laid header and stretcher alternately, with two cast iron hollow dowels let into the beds of each joint to unite all firmly together, and the part in which the heel-post of the gate turns well rubbed to a smooth water-tight surface. The reversed hollow quoins, so called from being intended to receive the gates in a reversed position, are of Bramley-fall stone, dressed and set in like manner, but without dowels.

The foundations of the bridge are brought solid to the proper level, and then divided by partition walls of stonework into four pits, each about 4 feet wide, to receive the ends or *tails* of the bridge when up.

Lock gates. Plan, No. 11.

The lock gates are partly of English, partly of African oak, from the difficulty of procuring the former timber of the requisite curve and size. They are framed and secured together in the usual way, with 3 inch fir planking closely jointed and caulked on one side, and $2\frac{1}{2}$ inch fender planks on the other. The gates were completely fitted on shore, and having been taken apart, were reframed in the bottom.

Each gate is hung at top with a wrought iron collar in a cast iron anchor let into the stonework; and fitted to the lower extremity of the heel-post is an iron socket, which turns on a brass pivot fixed in the platform, the outer end of the gate being supported by a brass roller, 12 inches diameter by 4 inches wide, fitted with an adjusting screw, revolving on a brass segment let into a cast iron one screwed down to the platform; the socket and shoe at the foot of the heel-post being of cast iron, a brass circular plate, $1\frac{1}{4}$ inch thick, is let into the bottom quoin, to protect the stone from injury and prevent leakage. The gangway or footpath is supported on cast iron brackets, and has a chain and stanchion fence on each side.

The machinery for working the gates, which is fixed in a cast iron box on

the side of the lock, consists of a 7 inch pinion working into a spur wheel 4 feet diameter, on the axis of which is a cast iron roller, 3 feet long, and varying from 12 to 9 inches in diameter; round this a $\frac{3}{4}$ inch chain winds, and passing under a roller at the bottom of the well, and over another similar roller in the face of the wall, is secured to the gate. There is also a counterbalance weight and chain, as in the other locks.

There are two sets of sluices to each gate, with three doors in each set, working on brass facings, in iron grooves, and so constructed that one set is raised whilst the other is lowered; which is done by the sluice-rod connected with the screw at top having a rack upon it that turns a spur wheel working into another rack attached to the other sluice-rod. By the disposition and mode of adapting the sluices to the spaces between the bars, a capacious opening is obtained without weakening the gates, and one man can perform the work of two in the ordinary way, in less than half the time,—an important consideration where economy and despatch are required. The machinery ought to be completely enclosed, to prevent chips or other floating matter getting inside, for want of which, one of these racks was broken soon after the dock was opened; and there should also be a stop to keep the sluices from falling into the bottom of the lock in case of accident.

Each gate complete, it is calculated, weighs upwards of 20 tons, or each pair 40 tons; the whole weight resting on the platform, which has not, however, settled in the least, but is now as level and perfect as when first completed. This, it need hardly be observed, is a most essential point in the working of large gates that move on friction rollers at the bottom, as is also the perpendicularity of the hollow quoins. To effectually ensure the latter point, Mr. Walker judged it expedient to have all the hollow quoins securely land-tied; this was done by putting a 6 inch landing, or flag, about 12 feet long by 8 or 10 feet deep, vertically behind the walls at the hollow quoins, with three 2 inch tie rods, let through and secured to the flag by means of nuts and screws and a wrought iron plate extending its whole length, the other ends of the rods taking hold of the anchor and being cramped into the stonework. Three similar tie rods are secured in like manner to the landing on the reverse side, having a connecting ring at the outer end by which they are united to a single tie extending to a row of piling about fifty feet from the side of the lock, like that for securing the mooring rings in the dock walls, but with shorter piles.

Reversing gates. The reverse hollow quoins and pointing sills, alluded to above, are for facilitating the repairing of the lock when necessary; in which case the gates will be removed into these quoins, so that the water may be pumped out of the lock for the repairs, without interrupting the business of the docks. This plan was first adopted by Mr. Walker at the Commercial Docks in London, where the gates were lifted by barges, and removed in a vertical position into the reverse quoins, and were ready for emptying the lock in one tide. The arrangement is simple, and attended with but little extra expense,—points that cannot fail to recommend its adoption.

Bridges. The bridges over the locks are on the balance or lifting principle, and consist of eight cast iron ribs, 9 inches deep at the centre or meeting by $1\frac{1}{2}$ inch thick in the plain part, and 2 to 3 inches at the edges, connected together by two sets of cast iron crosses to each half or leaf, the lowest being close to the abutment, by hollow pipes and bolts nearer the middle, and by the meeting plates, which fit together with a tongue and groove. When the bridge is down, the under side or soffit of the ribs forms an arch of 36 feet 6 inches span, and 3 feet 6 inches rise, resting on cast iron abutment plates fixed in the masonry at the sides. From near the axis, the ribs curve down below the fixed part of the bridge, and terminate in boxes filled with kentlidge, by way of counterbalance, each box being attached to two ribs. The axis on which the bridge turns is 9 inches square, with five turned bearings working in plummer blocks bedded on the stonework, the centre being 5 feet 3 inches from the side of the lock. The fixed part of the bridge is supported by iron joists resting on the division walls of the pits above described. The roadway is formed very much as in the bridge over the Old dock lock.

The bridge is lifted by means of four crabs, two on each side; the handle is applied to a 6 inch pinion, which works into a spur wheel, 4 feet diameter, having on its axis a 12 inch pinion, which works into a toothed segment, 5 feet 9 inches radius, fixed to the outer rib of the bridge.

When the bridge was nearly finished, it was found that a variable counterbalance weight was necessary in addition to the kentlidge, to render it nearly on an equipoise in all positions; this is effected by hooking to the tail two chains, which passing over pulleys fixed in the stone work at the back, and from thence over two other pulleys on the dock wall, are attached to a chain, composed of heavy flexible links, hanging into the bridge pit; when the bridge is up, the chain is just clear of the bottom, and assists by its gravity to draw

it down, and as the bridge descends and less balance is required, the weight of the chain, by falling on the bottom is reduced accordingly, till the kentlidge alone acts. In raising the bridge, exactly the reverse of this takes place. The weight of each bridge is about 100 tons; one half or leaf is usually opened or shut by three men in half a minute, but in an emergency two can do the work.

In comparing the balance with the swivel bridge, it may be observed that the former will work longer without adjustment, and is also stronger, from bearing more firmly upon its abutments; but it is more affected by the wind, the original cost is greater, and double the number of men are required to work it.

The bridges and lock gates were constructed by Messrs. Hunter and English, Millwrights, of Bow, London, who deserve credit for the complete and workmanlike manner in which they executed their contract; the ironwork was cast at Alfreton, Derbyshire.

Quays. The part of the backing for a width of a yard next the dock and lock walls is composed of the best clay or loamy earth, well rammed, so as to be water-tight, and the top of the quay afterwards levelled and trimmed, with a declination of $\frac{3}{4}$ inch in a yard from the side of the dock, covered for a foot in thickness with Hessle-cliff stone and shingle gravel, and having a paved channel towards the outside, with proper grates for the rain water. The quay is nearly level with the streets, on the east side of the dock, but six or seven feet above them on the west side, where it is supported for a considerable distance by a retaining wall.

There is a post and chain fence round the dock, about 15 feet from the side, and a railway is laid outside the east quay, within 5 feet of the footpath, to connect the railways of the Old and Humber dock, as already noticed.

Moorings. Plan, No. 8. On the east side of the dock, at intervals of about twenty yards, there are wrought iron mooring rings, fixed in front of the wall underneath the coping, and coupled to a wrought iron tie rod, the outer end of which is secured to a waling, behind a row of piling driven at some distance back. The ring is prevented from being lifted, by a wrought iron vertical plate sunk in and secured to the stonework by means of three dovetailed screw bolts, let into the wall. This plate being convex, and projecting a little from the wall, at the same time answers in some measure the purpose of a fender. The rings make very durable and excellent moorings, and have

besides the advantage of keeping the quays clear of ropes and chains, which are always an annoyance to business.

The moorings for the other parts of this dock, in consequence of the Company having had timber on hand, are oak posts, about 18 feet long, and 15 to 18 inches diameter near the top, fixed about 12 feet from the side of the dock, and secured by two Memel land ties, 9 by 6 inches, about 30 feet long, and diverging outwards, like the letter V, so as to be about 10 yards apart at the outer end, where they are bolted to a sill behind piling, nearly in the same manner as the ring moorings. The timber underground is all *charred*, for preservation. The moorings to the locks are either of small cannon or of Bramley-fall stone, 2 feet diameter, and are 3 feet 6 inches high.

Buoys. There are six buoys for warping and mooring vessels in the dock; they are 6 feet 6 inches square, by 4 feet 6 inches deep, made solid of Memel logs, with a casing of 3 inch fir planking spiked on tarred woollen felt, and the joints caulked. The ring is secured to a wrought iron bolt driven through the centre of the buoy; underneath hang a shackle and chain 9 yards long, the lower end of which is fastened to a strong timber framing bolted to four piles, 20 feet long, driven below the bottom of the dock.

Sewers. There are two main sewers for draining the quays and some parts of the town adjacent; that on the east side of the dock is 9 feet below the coping, and extends from Whitefriar-gate to Myton-gate, where it joins the Humber dock sewer. The other commences at the west side of Whitefriar-gate bridge, and joins the town sewers near the Dock Company's workshops on the west side of this dock; its bottom is 12 to 13 feet below the dock coping.

The sewers for draining the bridge pits are 2 feet wide by 3 feet high in the middle; the pits on the east side being 2 or 3 feet below the bottom of the sewer, the water has to be pumped out occasionally; but on the west side, the drainage by the new sewer is effectual.

A scouring sluice near Postern gate cleanses the sewer on the east side of the dock, and another near St. John's church, that on the west. These sluices are both alike, and of cast iron, 3 feet 3 inches wide by 3 feet high inside, sliding in a cast iron groove in the face of the dock wall, and worked by a screw: their bottoms are 9 feet below the coping, and there is an oak frame with folding doors on the outside to protect the sluices, which communicate with the main sewers by a culvert, 3 feet square. The sewer at Postern gate

is provided with two of these sluices, by opening one and shutting the other of which, the scour is to the north or south as may be required.

The sluice at the east end of St. John's Church was built at the expense of the commissioners under the Myton Improvement Act; the water, after passing along part of the Company's sewer, cleanses several others in Myton, and proceeding still further westward, discharges itself into the Humber at the general outfall in Lime-kiln Creek.

Water pipes. The pipes for supplying the town with water, which formerly were across the site of Whitefriar-gate lock, were removed while the works were in progress, and laid across the coffer-dam, as noticed before. In building the lock, a cavity, 2 feet 9 inches wide by 15 inches deep, was formed in the face of the stonework, across the bottom and up the sides to the level of high water of neap tides, and in this cavity two 8 inch cast iron pipes were laid, and secured to the stonework by a flanch cramped down at each joint; the space round was then filled in solid with brickwork, and covered with cast iron plates, bolted to the masonry. There are two bonnet pipes at the middle of the invert, made a little deeper than the rest, to contain any sediment that may remain, and so formed that the top can be taken off and the pipe cleansed by means of the diving bell; but to prevent any great accumulation, there is a small chain inside the pipes, by drawing which backwards and forwards it is supposed the sediment will be disturbed, and carried away by the force of the water. From the level of high water of neap tides, the pipes are built inside the wall, and carried up in a slanting direction to the height of the under side of the coping, near which they are joined by the regular mains leading from the water works into the town. Before these pipes were used, they were proved by means of the force-pump of a fire-engine, to a pressure of upwards of 200 feet of water.

Gas pipes. About the end of 1828, the Hull Oil Gas Company requested permission to lay a gas pipe under each of the Junction dock locks; this was granted them on certain conditions, and the Dock Company also resolved to lay two pipes in each place at their own expense, in order to prevent the possibility of a monopoly, and so at all times secure to the town and its environs a supply of gas at a reasonable rate: as the locks were at this time nearly completed, the work was attended with some difficulty, and much greater expense than if it had been done at an earlier period.

The provision made at the two locks was nearly the same; we shall describe that at Whitefriar-gate. In the first place, there was sunk, on each side at the north end of the lock, a shaft or well 30 feet deep, *steined* with brickwork, at the bottom of which an aperture was made under the foundation of the walls to receive the pipes; a trench was then cut across the bottom, and two rows of piles, 9 feet asunder, driven down 4 feet below the dock sills; transverse cap sills were next bolted on the pile heads, and blocking sills firmly spiked to them, on which 10 inch pipes in 9 feet lengths, with spigot and faucit joints, were, after being proved, laid with a declivity of 12 inches from side to side, to allow the sediment from the gas to run to tar cisterns provided at the bottom of the wells; the cisterns that belong to the Dock Company being on one side, and the Gas Company's on the other. In order to guard the pipes from injury, two longitudinal sills, 9 inches wide by 17 inches deep, and extending from wall to wall, were fixed, one on each side, on the transverse sills, and brickwork laid in the foundations as high as the under side of the pipes, which were then surrounded with a 4½ inch brick ring set in Parker's cement, and the rest built up with brickwork to the under side of the longitudinal sleepers, which were connected together at top by cross ties. The whole was afterwards covered with earth to the level of the dock bottom, the openings under the walls closely bricked up, and the wells coped and covered with oak planking. The tar cisterns were laid on large 6 inch flags, and had short pipes at the side and top to unite with the horizontal and vertical gas pipes; these pipes not having yet been wanted, are still unconnected with the street pipes, but this can soon be done when required.

Breach in coffer-dam. It has been before observed, that a preventer dam was made across the Myton-gate lock-pit; for further security, as soon as the south gates were hung, they were ordered to be securely braced, to prevent any irruption of water from the Humber into the new dock. The coffer-dam at the Whitefriar-gate lock being less extensive, was considered safer, and it was at first thought the bracing of the gates might be dispensed with, but the contractor having prematurely begun to remove the temporary bridge, with a view no doubt to expedite the completion of the work, the coffer-dam being connected therewith was placed in jeopardy, and it became necessary that these gates should also be securely braced. This precaution was soon found to be of the utmost advantage both to the work and for the safety of the shipping.

The following spring tides, in the morning of 21st March, 1829, there

appeared a small leakage under the east end of the coffer-dam, which it was attempted to stop by treading in a quantity of tempered clay, but without success, as the leak still continued, and in three hours there were several feet of water between the dam and the lock gates; the leakage then increased very rapidly, and filled the above space so fast, that for the safety of the gates, it was thought advisable to draw the sluices and let the water flow into the dock: about the same time the sluices of the Old dock gates were also opened, to lower the water in that dock, then about 19 feet deep on the lock sills, in order to reduce the pressure upon the Junction dock gates; but the breach under the dam soon after became so extensive as to undermine the Old dock wall, and in the course of the forenoon a length of about 60 feet of it fell down. This in some measure stopped the leak, and the water rose more slowly afterwards; but the succeeding tide it was nearly on the same level in the Old and Junction docks.

Happening as it did, near the conclusion of a great work that had been so far successfully carried on, this accident is to be regretted, and the more, as it might certainly have been avoided by deferring the removal of the temporary bridge a week or two longer, when the works would have been in such a state as to have allowed the dock to be filled with water in the regular way; yet the damage might have been infinitely greater, had not the Junction dock gates been closed and secured previously to the accident; it was this, indeed, that prevented the dam from being blown up altogether, in which case, from the tremendous rush of water through the lock, the consequences to this part of the work would in all probability have been most disastrous, while the shipping in the Old dock near the dam must inevitably have been swept with violence into the lock, and most serious damage been the result.

On being apprised of this accident, Mr. Walker repaired to Hull without loss of time, and finding the works so far advanced that they might be completed with the diving bell, advised the immediate removal of both coffer-dams and temporary bridges, and that the materials left in the bottom of the dock and locks should be taken out by the bell at the same time. He also recommended that the Old dock wall should be rebuilt upon piles, about 11 feet below the top of the wall, having a row of close piling with a substantial wale in the front, well land-tied, with cross sleepers and planks over all; this was accordingly done, and a stone string course laid on the front piling, upon which the brick wall was erected in the course of three or four weeks.

Removal of temporary works.

In removing the temporary bridges and coffer-dams, the piles were principally drawn by the engine crabs, with double blocks and chains, and so firmly did they hold, that some of them required sixteen men with four crabs to move them, but in general half this power was sufficient; after the piles were started, one crab with four men (assisted by the buoyancy of the water) accomplished the business. The power applied to some of these piles was not less than from fifteen to twenty tons. There being occasion in the course of the work to draw several of the sheeting piles in the Whitefriar-gate lock pit, a 4 inch screw was used, and one of the piles, 14 feet long by 12 inches wide, required, on the most moderate calculation, a power of 18 tons to draw it, the soil being nearly a pure sand; another pile could not be drawn by even a greater force, until a hole was dug round it, but the others, being in softer ground, moved more easily. In examining the sheeting piles when drawn, we found the points (none of which were shod) generally in a good state; a few, which were driven into a sheer black sand, bruised a little, and some of the grooves, originally 2 inches wide, increased to 3 inches, from having been forced outwards by the tongue in the hard soil.

After the dam and bridge piles were all drawn, and the part of the puddle above water removed, the remainder of the puddle and the earth at the foot of the dams were taken up by the dredging machines.

Dock opened.

The dock was publicly opened on the 1st June, 1829, being little more than two years and a half from the commencement of the work.

Mortar and lime.

The Warmsworth having been represented as a good water lime, the work was begun with mortar made from it and sand only; but from the bad state of similar mortar in the Humber dock walls, when taken down, and from some experiments, the lime appeared not to answer the description given of it, and Mr. Walker recommended the front of the dock and lock walls, to be set in pozzuolana mortar, which was accordingly done. At this time the greater part of the east wall of the dock, and a part on the south side of St. John's Church, were as high as the under side of the stonework, and it was observed that, notwithstanding the thickness and solidity of the walls, the water in very wet weather found its way through, so that they were exceedingly damp even in front, and in several places the water literally ran down the face of them; this was ascribed to the mortar and grout not hardening sufficiently, as in all cases where the front was set in pozzuolana mortar,

although the walls were a little damp in places, the water never penetrated through.

It may be proper in this place to state very briefly the result of some experiments on various kinds of mortar, which were made by the writer at Mr. Walker's request. The specimens were in small flat cakes, dried for a few days before being put into water. With respect to the quality of the lime, but little difference was found between the Warmsworth, the Weldon, and Fairburne; none of them mixed only with sand ever hardening in water, but on the contrary, dissolving quite in the course of a few weeks. Experiments were also made with these limes mixed with sand and pounded bricks or brick dust; with sand and *minion*, or pounded iron scales; and with sand, pounded scales, and bricks, in various proportions; but none of these different compositions shewed any tendency to become hard in water, and were indeed little better than lime and sand only. Several specimens made with the same kinds of lime mixed with sand and pozzuolana in various proportions, were then tried, and it was found that one of lime, one of pozzuolana, and two of sand, made an excellent mortar, either in or out of water; but, for economy, a mortar composed of two of lime, one of pozzuolana, and four of sand, was afterwards adopted, which, although it did not indurate quite so soon, retained its hardness in the water, and was but very little inferior to the former. Some experiments were also made with mortar of Haling lime and sand only, which, though superior to that made with the Warmsworth or Weldon lime, was by no means to be compared with the pozzuolana mortar, and as the expense was nearly the same, there was no hesitation in giving the latter the preference.

Stone. A few words descriptive of the stone used may not be improper. The Bramley-fall, got from an extensive quarry on the side of the Leeds and Liverpool canal, about four miles west of Leeds, is a coarse sand-stone, or mill-stone grit, of an excellent quality, and in durability as a building stone in all situations, perhaps inferior to none in this country except granite. Kirkstall Abbey, which is near seven centuries old, is built of it, and although the building is now a ruin, the stone generally is very perfect and entire. The Old bridge of Leeds is built of a similar stone; this structure has been twice widened, but the original part is very ancient, and still in a good state of preservation; as are also some of the locks on the Aire and Calder Navigation,

which have been erected more than fifty years. The Barnsley and Whitby are both fine sand-stones; the former, a sharp grit, much in use for grind-stones: they are generally used in their immediate neighbourhoods for building in water and otherwise, and some beds of each are very durable; but they are both much inferior in this respect to Bramley-fall. The Dundee stone used in the hollow quoins is a fine grained close stone, very hard and durable, though on account of its laminated structure, improper for coping, and if quarried a little before or during winter time, liable to be rent by the frost. There were several other kinds of stone brought on the ground, particularly the Mexborough, but being of inferior quality, they were only used in the inverted arches of the locks, and other parts constantly under water. Whilst upon this subject, it may be proper to observe, that by fronting the walls with stone above high water of neap tides, they have been rendered exceedingly durable as compared with a brick facing, without materially adding to the expense.

Lockage. The passage of a ship through the lock, including the opening and shutting of the bridge, usually occupies about five minutes, but frequently little more than half that time; six to eight heavy laden ships, besides small craft, have passed through Whitefriar-gate lock in an hour, proper time being also allowed for the passengers and traffic over the bridge, which is here very great.

In stating the waste of water, or leakage, it should be noticed that there are seven scouring sluices besides the eight sluices of the entrance lock gates. From a series of observations made on Sundays, when there is no waste by locking, the leakage of the three docks is about three quarters of an inch per hour in spring tides, and half an inch in neaps.

Mud. The accumulation of mud in the Junction Dock has hitherto been very little, certainly not more than at the rate of an inch a year; so that the total quantity of mud in the three docks now, is not so great as in the two docks heretofore; and as the steam dredger has now a ready communication with the different docks, it performs the whole work, the horse machine having been altogether dispensed with since 1829.

State of walls. Having before described the state of the mortar in the Old and Humber dock walls, I shall here give a very brief description of that in the

Junction dock. The common front mortar, especially that used late in autumn, all suffered more or less injury from frost; and no part of it, so far as there has been opportunity of examining, has hitherto, where damp, acquired any considerable degree of hardness; nevertheless, as the walls are all substantially founded and solidly built, it is confidently expected that the mortar will continue to indurate till the whole becomes one compact body. The pozzuolana mortar in the front of the walls, even before the water was let in, was in general hard and good, the only defective part being in the west end of the dock, where the wall was damp in consequence of being backed with wet soft earth; some part of this mortar, being used late in the year, was a little perished by the frost, and required fresh pointing, but the front of the walls has been frequently examined since the dock was opened, and the joints found every where as perfect and entire as at first. In some parts of the work, accidentally injured by the shipping, and taken down and rebuilt, the pozzuolana mortar was found in a good state, although not so hard in the interior as in the front; the mortar in the beds of the stonework, also, was more indurated than in the vertical joints, and for the most part adhered much firmer.

Town-walls or fortifications.

In the course of the works of the Junction Dock, a part of the old fortifications on the east side was cut through and taken down; from their antiquity they may be deemed not unworthy of notice. The walls are said to have been originally built of stone in the time of Edward the Second, but repaired and strengthened with bricks in Richard the Second's reign, when the art of brick-making was revived in this country. The bricks were about 11 inches long by $5\frac{3}{4}$ inches wide, and $2\frac{1}{2}$ inches thick. The mortar was of two kinds, one composed of lime and sand only, the other of lime and powdered bricks or tiles, with very little sand; both were, with a very few exceptions, extremely hard, the latter being the more so. The mortar appeared to have been used in a very soft state, or as grout, but by no means well tempered, small lumps of pure lime, resembling hard tallow, being interspersed in great abundance. In three or four of the bottom courses, and nine to eighteen inches in width at the back of the wall, where it was in a damp state, it had not set in the least, and at the bottom in particular, appeared like pure sand, while the neighbouring parts, being dry, were particularly hard, and united together like a rock. It is a generally received opinion, that the extreme hardness of the mortar in old buildings is owing entirely to its having been

much better tempered in ancient than in modern times; although there is no doubt that this is a most essential point in all kinds of mortar, it is conceived that the superiority is caused chiefly if not wholly by *time*, and that mortar continues to harden in certain situations probably for centuries. The foundations were eight or ten feet under high water, and in some parts were on small piles, the rest being on the natural ground. The piles were 5 or 6 feet long, and 6 or 7 inches diameter, some of oak, some of fir, and the hearts of both kinds quite sound and of a blackish colour, but the sap much decayed.

Tides and currents in docks.

It was expected when the Junction dock was opened, that it would, on account of its situation, be in a great measure supplied with water from the Humber, but the contrary has been the case, the principal supply being certainly from the river Hull, as is proved by the altered quantities of mud deposited in the Old and Humber docks already noticed; there being an annual increase of mud in the Old dock of about 4,000 tons, and a decrease in the Humber dock of about 6,000 tons, since the Junction dock was opened, as compared with former years. This also shews, that even the Humber dock is in part supplied from the purer source of the Hull.

As a further elucidation of the nature and course of the tides since the Junction dock was opened, the following observations are submitted. During the night tides and on Sundays, when no business is done in the docks, the Humber dock gates are secured fast together, in order to shut out the muddy waters of the Humber. On one of these occasions, very soon after this contrivance was adopted, I noticed that, the water being level on the two sides when the gates were thus shut, the flow was faster on the side next the Humber for the first quarter of an hour, at the end of which the difference was at its maximum of about three inches; the water on the opposite sides then began to approximate again, and at the end of fifteen minutes more it was again exactly level throughout. This observation has been since repeated with nearly the same result, though varying a little, according to the state of the tides, and as there may be freshes in the river Hull; in one instance the difference of level was as much as four inches. It appears, then, that the principal supply from the Humber is in the first half hour after the tidal water arrives at the level of the water in the docks, and this agrees with the current or course of the tide through the different locks. I have frequently set off from the Old dock lock at the time the tidal water opened the gates and began to flow into the dock, and have walked slowly on to the Whitefriar-gate lock, where the water had

just commenced running very gently into the Junction dock; proceeding forward to the Myton-gate lock, I have generally found the water stagnant, but in the course of a few minutes there appeared a very slow motion towards the Humber dock, and by the time I have arrived at the Humber lock, or about half an hour after leaving the Old dock lock, the water was running gently towards the Humber. It should be observed, that in neap tides the above currents through the locks are always slow, but in spring tides, and when there are freshes in the Hull, the velocity is often as much as three quarters of a mile per hour, and sometimes even more. The current into the Old dock through the entrance lock is also considerably increased since the Junction dock was made; from observations soon after the opening of the latter, as to the exact level of the tide at the entrances to the Old and Humber docks, it was found that, on an average of several tides, the gates of the former were opened by the rising tide about three minutes before those of the Humber dock.

Before leaving the subject of the tides, I may notice a curious fact, founded upon repeated observation; viz., that about three hours before and after high water, there is sixteen feet water on the Humber, and only ten feet on the Old dock sill.

Conclusion. Having thus endeavoured to give a concise account of the Harbour and Docks at Kingston-upon-Hull, with reference to that department more immediately connected with the object of the Institution for which this paper has been drawn up, I cannot conclude without again briefly adverting to the great and important advantage the town and port have derived from the improvements described.

It is but little more than half a century since the first dock was completed; before that time, the river Hull below the bridge was the only safe harbour in the port, and in this narrow confined space the shipping and small craft were so crowded together, that it was often with great difficulty they could have access to the quays to take in or deliver their cargoes, and damage was sustained by the larger vessels from grounding every tide. It also sometimes happened that the harbour was incapable of containing all the shipping that frequented the port, in which case they were laden and delivered in the Humber by means of craft, at the expense of much delay and considerable additional charges. These inconveniences, and the want of a legal quay, with the complaints they gave rise to on the part of the revenue officers, at length led to the

formation of a dock, which in time was followed by another. But, extensive and commodious as were the Old and Humber docks, for want of a ready passage between them they were still incomplete,—the Junction dock has perfected the communication; and instead of being surrounded, as of old, by fortified walls and deep ditches, which (their occupation being gone) had latterly become stagnant pools, the common receptacles for filth and nuisance, the town is now encircled by the rivers Humber and Hull, and three spacious and commodious docks; improving the public health by the assistance afforded to drainage through the liberality of the Dock Company, and rivalling, in convenience for mercantile men and facilities for the despatch of business, those of any port in the kingdom. These, and the means of inland communication, enjoyed or in prospect, with a district peculiarly rich in minerals and manufactures, added to its situation on so noble an estuary, and its contiguity to the continent, cannot fail to maintain the eminent rank Hull has hitherto held among British ports.

DOCKS.

	Length.	Breadth.	Area.			Number of Ships.
	Feet.	Feet.	Acres.	Roods.	Poles.	
Old Dock . . .	1703	254	9	3	29	100
Humber Dock . .	914	342	7	0	24	70
Junction Dock . .	645	407	6	0	5	60
			23	0	18	230

BASINS.

	Length.	Breadth.	Area.		
	Feet.	Feet.	Acres.	Roods.	Poles.
Old Dock . . .	213	$80\frac{1}{2}$	0	1	23
Humber Dock . .	267	435	2	2	27
			3	0	10

ENTRANCE LOCKS.

	Length.		Breadth.		Depth of Water on Sills at Neap Tides.		Spring Tides.	
	Feet.	In.	Feet.	In.	Feet.	In.	Feet.	In.
Old Dock . . .	120	9	38	0	14	0	20	0
Humber Dock . .	158	0	42	0	20	0	26	0
Junction Dock . .	120	0	36	6	14	0	20	0

BRIDGES.

	Each Footway.		Carriage-ways.		Width inside Railing.		Total width outside.	
	Feet.	In.	Feet.	In.	Feet.	In.	Feet.	In.
Old Dock . . .	3	6	7	6	14	6	15	0
Humber Dock . .	2	8	6	11	12	3	12	6
Junction Dock . .	4	0	15	3	23	3	24	0

WAREHOUSES AND SHEDS.

	Length.	Breadth.	Area.
	Feet.	Feet.	Superficial Yards.
Warehouses, Old Dock . . .	345	. . .	2,251
Sheds, Ditto	{ 143 492	23 } 23 }	1,623
Sheds, Humber Dock . .	754	25	2,095

QUAYS.

	Legal Quays.	Totals.
	Square Yards.	Square Yards.
Old Dock . . .	18,160	29,000
Humber Dock . .	8,830	17,639
Junction Dock . .	. . .	15,643
Humber Dock Basin .	. . .	8,419
	26,990	70,701

II. *On the Locks commonly used for River and Canal Navigation. By Mr. W. A. Provis, M.Inst.C.E.*

1*st.* *Simple dam locks.*

The earliest approximation to what is now known by the name of lock, consisted of a simple dam formed across the bed of a river, so as to raise the water to such a height as to allow vessels to float along it. Where the river had a considerable fall with a strong current, it was necessary to have these dams at short distances from each other, otherwise the requisite depth of water could not be obtained. As the whole space between two of these dams was in fact the lock, it was necessary in passing from one level to another, to run down the water for the whole of that distance, thereby causing considerable delay, and a waste of water that would now be considered a serious evil. In China these dams are very common; they have also been used on the continent of Europe, and what is not a little extraordinary, are at this very day in use in our own country. My brother having given me a description of one of these which he saw on the river Ouse, near Tempsford, in Bedfordshire, I here insert it. The river is somewhat contracted in its breadth by a wall on each bank, between these two a third, or middle wall, is built, with cutwater ends. At the middle of each of the passages formed by these walls a sill is extended across the bottom of the channel, and pile planks are driven along its upper side, with the necessary sheeting to prevent the water getting under it. On one of the side walls a beam similar to the balance of a common canal lock gate is placed, which turning horizontally upon an axis, one end is made to abut against a projecting piece of timber which is fixed in the middle wall; this beam and the before mentioned sill form the top and bottom of a frame, on the upper side of which a row of vertical planks is placed, one at a time, so as to form the working dam; the other space has a piece of timber fixed at the top of its two side walls, corresponding with the sill below, and vertical planks are placed between these in the same manner as at the other opening, but as vessels are not intended to pass through more than one of the openings, the upper beam in the other is fixed. The use of this second space or opening is to allow the water

to be run off more expeditiously, particularly during floods. In going up the stream, a vessel passes the place where the temporary dam is to be formed, and then the moveable or balance beam is swung round, the vertical planks put down, and the water thereby completely stopped till it rises to such a height as to run over the top of the dam; before this takes place, the vessel has sufficient water, and she proceeds on her voyage to the next dam above; these dams are kept open when there is no vessel near, and at all other times when there is sufficient water for navigation without penning it up. It may appear, at first, that it would be more advisable to have a complete gate similar to those now generally used on canal locks, but a gate would be attended with these inconveniences, that the water could not be run out in so short a time by its paddles as it can when the whole space which the gate would occupy is available, and also the difficulty of opening against a rapid stream a gate of the required size. Though this principle of damming up the water was a valuable improvement in our river navigation at the time it was introduced, yet as it is only applicable when water is abundant, and must at this time be considered a very rude mode of passing from one level to another, it requires no argument to shew that it must soon give way to the adoption of our modern locks.

2d. Lock with a double set of gates, but no chamber walls.

The evils attendant on the dams just described were in a great measure removed by the introduction of double sets of gates or sluices; the upper set being constructed so near to the lower, as only to leave room enough for the vessel or vessels to float between them. Framed gates were also used instead of separate beams and planks, because the space to be emptied or filled was so small, that a very short time was required to pass the water; and there was no stream of sufficient strength to prevent their being easily opened. Where these locks are intended for rivers, it is usual to make a side cut or artificial canal for the purposes of the navigation, and to leave the river course for the passage of the surplus water. A quick bend of the river is generally chosen for one of these cuts, and to keep the water in the upper part of the river to a sufficient height for navigation, a dam or weir is made across the old river course at or below the point where the artificial cut quits it. The lock is then built at the most convenient part of the cut, and its fall made equal to the dif-

ference in the levels of the water at the top and at the bottom of the dam or weir. When a vessel is going up the river, she floats along the cut, and passes between the lower gates into the lock, the lower gates are then closed, and the valves or paddles of the upper gates being opened, the water flows into the lock, and rises to the level of the upper part of the river; the upper gates are then opened, and the vessel floats out of the lock. Of course the reverse of this operation would conduct a vessel down the river.

It will be obvious to every one, that the sides of these locks must rise above the level of the higher part of the river, otherwise the water would flow over and injure them. The gates should also rise above the highest water's surface, or the water would flow over their tops and probably into the passing vessel, so as to endanger its safety or damage its cargo. It has been common to make the gates no higher than the water's surface, but the before mentioned inconveniences shew the necessity of making them higher, and of constructing the dam or weir of sufficient breadth to take off with facility all the surplus water.

The abutments for the gates have been made of timber, brickwork and masonry, but when the double set of gates was first introduced, it was usual to leave the space between the upper and lower gates unprotected by either timber or any kind of building. Of course the agitation of the water in the lock was constantly washing away the earthen banks, thereby causing a risk of their being broken down by such continued weakening; and by enlarging the space between the two sets of gates, it occasioned a loss of time in emptying and filling, as well as a waste of water.

3d. Lock with a double set of gates, and the sides of the chamber secured by timber.

To check the mischievous tendency of leaving the chamber unprotected, the side banks of many old locks have been in part secured by driving a row of piles along the base of each slope, and fixing planks at the back of them, so as to form a wooden wall for about half the height of the lock; but there is sometimes a risk in trying this experiment, for the space between the two sets of gates being frequently lined or covered with puddle, resting on a porous substratum, the water often escapes by the sides of the piles, and causes not only leakage but a danger of blowing up the lock. Examples of this sort of lock may be seen on the river Lea navigation.

4th. Common modern canal lock.

It was not until the construction of artificial canals became very general that locks were brought to any thing like perfection, for the difficulty of procuring sufficient supplies of water had been but partially felt when our inland navigation was confined to a few of the principal rivers.

When canals had spread themselves in various directions over the country, aud water became so scarce and valuable as to be the cause of much litigation and expense, it was necessary to be careful of every resource, and to use it with the strictest economy. For this purpose, the space between the upper and lower gates was contracted to such a breadth as only to leave room enough for the vessel, and the bottom and sides were constructed of brickwork or masonry, instead of sloping banks of earth. By these means the superficial area of the lock was reduced to very little more than that of the vessel, and consequently was as small as it could be made.

The difference of altitude between the upper and lower levels, where the locks are constructed, varies according to local circumstances. Where the ground is longitudinally steep and water plentiful, the locks are generally made of greater lift or fall than where the ground is comparatively flat and water scarce. It is evident that, where the superficial area of locks is the same, one having a rise of 12 feet would require twice the quantity of water to fill it that would be requisite for one of 6 feet. Having many locks, however, of small lifts instead of a few of greater, increases the expense as well as the time for passing them.

For narrow canals these locks are generally made about 80 feet long, and $7\frac{1}{2}$ to 8 feet wide in the chamber. On the Caledonian canal they are 180 feet long, 40 feet wide, and 30 feet deep. Locks are also constructed of every intermediate size.

Lock gates have till lately been made of timber; but in consequence of the difficulty of procuring it of sufficient size for those on the Caledonian canal, cast iron was partially adopted for the heads, heels, and ribs. Iron gates, cast in one piece, have been used on the Ellesmere canal, as well as others with cast-iron framing and timber planking.

Whether constructed in a single leaf, or a pair of leaves, the gates of locks are usually made to turn horizontally upon a pivot at the bottom of the

heel; but there is a singular exception at the locks on the Shrewsbury canal, where, at each end of the lock, a single gate is made to rise and fall vertically, in grooves in the side walls. A pulley is fixed on its axis about 12 feet above the lock, over this a chain is passed, one end of which is fixed to the top of the gate, and the other to a weight, by which the gate is so nearly balanced as to allow of its being worked up and down by one man. On entering or quitting the lock, the boats pass under these gates.

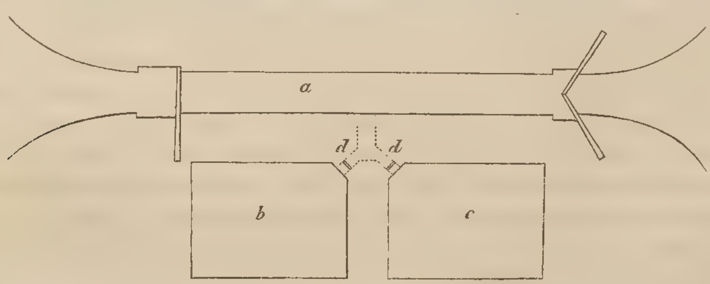
I am not aware of any lock in England of greater rise than 18 feet, but Tatham in his work on canals, (p. 164,) mentions one of 20 feet rise, built in 1643, by Dubie, between Ypres and Furnes, to connect the canals which bear those names. There are two pair of upper gates to this lock to guard against accidents.

On the Languedoc canal there is a celebrated circular lock, which has had more credit bestowed upon it than it deserves. The fact is, it is nothing more than a circular basin, into which three canals of different levels descend by common locks.

Various modifications of this principle have from time to time been adopted, either to save water, time, or expense.

5th. Locks with side ponds.

When water is scarce, it is common to construct side ponds, by which a considerable portion (in general one half) is saved. The usual number of these ponds is two, for it has been determined by experience, that when a greater number have been made use of, the loss occasioned by leakage and evaporation has sometimes been more than equal to the additional quantity of water retained.



In the accompanying sketch, *a* is a common lock, *b* and *c* two side ponds, (each equal to the area of the lock,) *d d* two culverts with paddles, each commu-

nicating with the lock and one of the side ponds. Supposing the lock to fall 8 feet, the bottom of the pond *b* will be 4 feet, and that of *c* 6 feet below the surface of the lock when full. If a vessel is to descend, it enters the lock when full, and the gates being closed, the paddles of the side pond *b* are opened, and the water flows into it till the level of the water in the lock is lowered, and that in the side pond raised, till they are the same, which will be when the water in the lock has sunk 2 feet; the paddles of the side pond *b* are then closed, and those of *c* opened; a similar operation then goes on till the water in the lock has sunk 2 feet more, when the paddles of *c* are also closed, and the remaining 4 feet of water in the lock is run into the lower level of the canal, through the paddles in the lock gates. When the lock is to be filled, the water in *c* is first run into the lock, which raises its surface 2 feet, the water in *b* is next run into it, which raises the surface another 2 feet, making together half a lock full, the upper half is then run down from the higher level of the canal.

6*th*. *Locks for the transit of vessels of different sizes.*

Where vessels of different sizes have to pass the same locks, three pairs of gates are sometimes placed instead of two,—the distance between the upper and lower pairs being sufficient to admit the largest vessels, and that between the upper and middle pairs being adapted to the smaller class. By this contrivance, when a small vessel is to be passed through, the lowest pair of gates is not used, and when a large vessel goes through, the middle pair of gates is not worked. Thus, it is evident, that the quantity of water contained between the middle and lower pair of gates is saved when a small vessel passes, compared with what would be required were the middle set of gates omitted.

7*th*. *Parallel double transit locks.*

But where the transit is great, much time and water may be saved by a double transit lock, which is, two locks placed close to and parallel with each other, with a communication between them, which can be opened or cut off at pleasure by valves or paddles.

As one of these locks is kept full and the other empty, a vessel in descending floats into the full one, the upper gates are then closed, and the water is

run, by means of the connecting culvert, into the empty lock, (the gates of which were previously closed,) till the water in the two locks is on the same level, which will be when each is half full; the connecting paddles are then closed, and the remaining half of the water in the descending lock is run into the lower canal. The next descending vessel has to be floated into the lock which remains half filled, and which consequently requires only half a lock of water to be run from the upper pond to raise it to the proper level, and then that half is transferred to the lock previously used, to serve the next descending vessel; but supposing a vessel to be ascending after the first descent, it will enter the empty lock, and receive a quarter lock of water from that which remained half filled: of course three-quarters of a lock of water is now required from the upper canal to complete the filling. If a descending vessel next follows, it enters the full lock, and its water is run into the lock which was previously left a quarter full, and when both have arrived at the same level, it is evident they will be each five-eighths full; and the succeeding descending vessel will require only three-eighths of a lock of water from the upper pond or canal. From these observations it will be seen that the double transit lock saves nearly one-half the water which a common single lock would require.

Sometimes the two parallel locks are made of different sizes, to suit the various description of vessels that may have to pass.

8*th*. *Locks connected longitudinally, commonly called a chain of locks.*

When loss of water is of no consequence, a considerable expense is sometimes saved, by placing the locks close together without any intermediate pond, for by passing from one immediately into the other, there is only required one pair of gates more than the number of locks so connected, besides a proportionate saving of masonry.—Thus, 8 connected locks would only require 9 pairs of gates, whilst, if they were detached, they would require 16 pairs; but to show that these cannot be adopted with propriety, excepting when water is abundant, it is necessary to observe that every two alternate ascending and descending vessels will require as many locks full of water as there are locks; for instance, if a vessel has just ascended, it has left all the locks full, a descending vessel then enters the upper lock, and when its gates are closed, the water is run down, but all the locks below being previously filled, they cannot contain it, and it consequently passes over the gates or weirs

of all of them into the lower canal: the vessel has by this means descended to the level of the second lock, the water in which must also be run into the lower canal, for the same reason as already stated. When the water of all the locks has thus been run down, an ascending vessel will require all these locks to be filled from the upper canal, which, however, will be retained in the locks ready for the succeeding vessel to pass down. From this it will be evident that where 8 locks are connected, a descending vessel draws no water from the upper canal, because the locks are previously all filled, but it empties 8 locks of water into the lower canal; an ascending vessel on the contrary empties no water into the lower canal, because all the locks were previously emptied, but it draws 8 locks full from the upper canal in order to fill them; consequently the passing of one ascending vessel, and one descending, requires 8 locks full of water.

9th. Other modes for passing vessels from one level to another,

By substituting machinery, either wholly or in part, have been adopted; but these have either failed entirely, or not been brought into general use.

III. *Improved Canal Lock, by* J*OSHUA* F*IELD*, *Esq., F.R.S., V.P.Inst.C.E.*

The numerous and extensive navigable canals by which this kingdom is intersected, have tended in a great degree to exhaust every natural source from which water for their supply can be obtained; this renders the further extension of these important channels of commerce difficult, and in many cases impracticable. Some canals are altogether supplied by artificial means at an enormous expense, others only in part, whilst the greater number, depending upon natural sources alone, are more or less in want of water, and consequently the navigation is interrupted during the driest season of the year.

To lessen the great loss of water by the common canal locks has long been a standing desideratum amongst engineers, and perhaps no subject has engaged more talent and ingenuity than the solution of this hydrostatic problem. Numerous contrivances have been resorted to, some to save the whole and others part of the lockage water; many of these are beautiful in theory, and perfectly successful upon a small scale, but when they have been tried upon the full magnitude they have uniformly failed, chiefly from the circumstance of the scheme involving some prodigious moving plunger or caisson, floated or suspended; and in most cases this vessel has been required to be perfectly water or air tight, and poised with the utmost precision,—conditions hardly to be obtained in practice, and if attained, the expense alone would defeat the object.

When the rough usage to which canal locks are subject is considered, and the ignorance of the persons necessarily employed in the management of them, it does not seem probable that any conservative lock will succeed until the whole apparatus shall be reduced to fixed masonry, and no other machinery employed than common gates and paddles, or sluices; for of all that have been invented, and for which upwards of twenty patents have been granted, none have been brought into practice for any length of time, except those of the side-pond class, which save half the water, and which, though less simple than the common lock, consist of the same parts, and are found completely manageable by the persons usually employed on canals. Having been engaged in the execution of the largest conservative lock that has been constructed, my mind has been long engaged in the pursuit of some more simple means of

effecting the same object, for very little reasoning on the subject will be sufficient to shew that every common lock full of water, let down from the upper to the lower level, possesses in itself a physical power or force sufficient to raise an equal quantity of water from the lower level to the height from which it has descended,—action and reaction, cause and effect, being equal.

The method by which I propose to render the descending lock of water available for raising an equal quantity is, in its simplest form, as follows: at a suitable distance from any common lock, in any direction I have a side pond or basin, of an area and depth equal to the lock and communicating with it by a large and long culvert, rather under the lower level; the diameter and length of this culvert must be such that it will contain as much water as the lock, each end of the culvert is to be provided with a sluice, shewn in the diagram, Fig. 1, at A and B. (Plate XII.)

The lock being full or equal to the upper level, and the side pond empty, or equal to the lower level, the operation will be as follows:—when the sluice or valve at A is opened, the head of water in the lock will very gradually put the water contained in the culvert in motion, the velocity accelerating by the laws which govern the motion of fluids, until the levels of the water in the lock and side pond coincide; at this time the column of water in the culvert will have acquired a velocity due to the height fallen, it will then continue to move forward with a momentum that will not be destroyed, until the water has risen in the side pond to the height from which it descended in the lock, abating somewhat for the loss of effect from the friction of the water against the sides of the tunnel, &c., the water gradually coming to rest, when the sluice *B* in the side pond must be shut to retain it,—the converse operation is performed by opening the sluice *B*, when the lock will fill and the side pond become empty.

The principle of this lock may be well illustrated by the vibrations of a pendulum, which in like manner, actuated by the force of gravity, falls to the lowest point with an accelerating velocity, when it acquires a momentum sufficient to raise it up the other side of the arc, nearly to the height from which it fell, the loss being only that arising from the friction of the suspending point and the resistance offered by the air.

It is from the close analogy it bears to the pendulum that I judge the culvert should contain as much weight of water as the lock, that it may acquire sufficient momentum; it may contain more, but I think it should not con-

tain less; thus the quantity of water raised will be equal to the quantity fallen, less the loss by friction in its transit;—the friction against the sides of a tube or culvert is simply as the diameter of the tube, while the area is as the square of the diameter, therefore the larger the tube the less in proportion will be the friction, hence the larger the lock the more complete will be the effect, and the operation of a model cannot be, like most other models of conservative locks, so perfect as a full-sized lock.

Although a lock upon this principle has not been executed upon the full scale, I have tried it in a model of sufficient magnitude to justify the greatest confidence of its perfect success.

The model consisted of two cisterns five feet long by twenty inches wide, having a communicating pipe of eight inches in diameter and forty-five feet long; a door valve, having a lever to open it, was fitted to each end of the pipe opening into the cisterns; a graduated scale was accurately placed in each cistern, and a ready means provided of adding to or taking from the water of either cistern as occasion might require—experiments were then made with various differences of levels, from twelve inches downwards, the results of which are here stated.

Difference of level 12 inches—the water rose in the opposite cistern		$10\frac{1}{2}$.
8	Do.	$7\frac{5}{8}$.
6	Do.	$5\frac{7}{8}$
4	Do.	$3\frac{15}{16}$.

When tried at less differences it apparently rose to the same height, and when both the doors or valves were left open, it continued vibrating nearly an hour before it came quite to rest; and it is remarkable that the vibrations, whether twelve inches or one-eighth of an inch, were performed in equal times, namely 10 seconds. This experiment was tried in 1816, and I have annexed a sketch of the apparatus used for the purpose. Fig. 2.

Having described the principle in its simplest form, and given the results of the experiments made with the model, I shall now point out several modifications that have occurred to me in applying it to the purpose proposed.

The column of communication in the model, and so far as spoken of hitherto, is straight; but this would remove the side pond to an inconvenient distance from the lock, and occupy much ground. This objection is removed by the plan proposed in Fig. 3, wherein the column forms a volute round the side pond or basin, by which means very little ground is required, and the

sluices or paddles at each extremity of the culvert are brought very near together.

Fig. 4 shews its application to a double lock;—here the culvert is carried in a large circle, under the bed of the upper level,—one lock forming the side pond for the other.

The next and last modification I shall notice is described in Fig. 5. The object here is to dispense with the side pond altogether. As this is not so obvious as the former methods, it may be necessary to refer to the letters in the sketch. Let *A* be a long culvert, leading from the lock up into the upper level at *B*, having a sluice at each end, as before; there is a branch near *B* leading into *C*, which is an open cut from the lower level. Now when a lock full of water is to be discharged, the sluice at *D* is to be opened, the water will then run along *A*, and out at *C*, into the open cut; when half the water has run out, a swinging valve, situated at *E*, must be moved so as to shut the passage into *C*, and open it into the upper level, *B*; the water having acquired its greatest momentum, will continue to run up into the upper level until the lock is empty, when *B* must be shut. The converse operation is thus performed:—open *B*, and the water will flow freely into the lock; when that is half full shut *B*, and the swinging valve *E* will open, and the column in motion will draw up water from the open cut, until the lock is full. This modification, I admit, is open to many objections, and is one I should certainly not adopt;—the methods described in Figs. 3 and 4, are I conceive best adapted for practice.

The principle upon which this lock depends is the same as that of the hydraulic ram of Montgolfier, much used in France for raising water a considerable height by a small fall. The experiments made by him, and those who have followed him, show that the loss by friction is not great, even in his pipes, which seldom exceeded two inches in diameter; this, with the results of my experiments with much larger pipes, leads me to expect the loss in a culvert of four or five feet diameter will be very inconsiderable. A calculation made also from the table given by Smeaton, of the head of water necessary to overcome the friction of pipes up to twelve inches' bore, at various altitudes, leads to the same result.

The time it would take to pass a barge, or to change the level of a lock upon this principle, would certainly not be longer than is required at present, and perhaps not so long.

I should imagine that a lock, well constructed upon this principle, having

the culvert very smooth, would save nine-tenths of the water, and that the change would be effected in less than one minute. On an attentive consideration of this subject, several methods have occurred to me of making the large sluices, or paddles, so as to be quickly and easily opened and shut, and of various securities in the management of so large a column in motion, with some necessary compensations, &c., which would be obvious to any one about to adopt it.

I beg to present the foregoing remarks to the Institution of Civil Engineers, in the hope that the idea therein suggested being generally known may lead to the practical adoption of the plan.

IV. *On the strain to which Lock Gates are subjected.* By Peter W. Barlow, *Civil Engineer.*

Having of late been engaged in estimating the dimensions of timber required for Lock Gates, I have been led to the consideration of the different strains to which they are liable, and the results of my investigations having, in some instances, been rather unexpected and interesting, I beg to lay them before the Institution of Civil Engineers, in the hope that they will prove of utility.

In England, of late years, lock gates of large dimensions have been constructed of an arched figure, with a view to increasing their strength; how far an advantage is gained by this construction, it is chiefly the object of the present paper to investigate. Previously, however, to entering into these enquiries, it will be necessary to explain the nature of the strains to which the common straight gate is exposed.

The best angle for the sally of lock gates made of straight timber is a subject which has already engaged the attention of some mathematical men, but I must observe, with respect to those investigations which I have had the means of examining, that they seem to be founded on data evidently incorrect. A common straight gate is exposed to two strains; one a transverse strain, produced by the weight of water at right angles to its surface, which is equal to half the weight applied in the middle; the other a strain in the direction of its length, produced by the pressure of the opposite gate upon its extremity. This latter strain, if the salient angle was of 45°, or the gates stood at right angles to each other, would of course amount to half the weight on the opposite gate, so that at this angle a lock gate has, in addition to the transverse strain, an equal strain in the direction of its length.

Before we can arrive at the angle at which, with given dimensions of timber, the greatest strength will be given to a pair of gates, it becomes necessary to know the amount of transverse strain produced by the end pressure of the other gate; or in a beam loaded in the middle, the additional transverse strain produced by a given degree of pressure applied at the ends. In order to ascertain this point precisely, it would be necessary to have a distinct set of experiments, which would not only be difficult to execute, but very uncertain

in their results; and as precision in this point is not necessary to the present question, I think, by the examination of M. Girard's experiments, we may arrive at it sufficiently near for our purpose.

These experiments were made upon a large scale by order of the French government, and although there appears to be some irregularity in the results, I have no doubt they are as correct as the uncertain nature of such inquiries will permit.

The following is an abstract of his experiments on the strength of oak baulks loaded at the end, and with the weight the same timbers would bear loaded in the middle, calculated by the rules given in Barlow's work on timber; by which a comparison can be made of the relative strength when subjected to a direct and transverse strain.

The timbers experimented upon by Girard were not in every case completely broken, but there is no doubt the weight they were subjected to was very little short of that which would have completed the fracture.

TABLE I.—ABSTRACT OF GIRARD'S EXPERIMENTS ON THE STRENGTH OF TIMBER LOADED ON THE END.

No. of experiments.	Dimensions of the Timber. Length.	Breadth.	Thickness.	Weight in pounds the beam bore applied to the extremity.	Weight in pounds the same beam would bear loaded transversely.	Ratio.	Remarks.
	FEET.	INCHES.	INCHES.				
1	8	6.21	5.03	93616	8598	·092	
2	8	6.39	4.17	94018	6078	·064	Broken.
3	8	6.21	3.99	69165	5390	·078	
4	8	5.23	3.89	50526	4325	·085	Broken.
5	8.628	5.15	4.17	50608	4900	·097	Broken.
6	7.549	6.02	5.15	115359	9980	·087	
7	7.549	6.21	5.05	103799	9909	·095	
8	7.549	6.12	4.085	73095	6396	·087	Broken.
9	7.549	6.21	3.99	63177	6336	·100	Broken.
10	7.549	4.96	3.99	44857	4924	·109	
11	6.471	6.12	5.24	87494	12366	·141	
12	6.471	6.21	5.15	87481	12013	·136	
13	6.471	6.21	3.99	87079	7392	·085	
14	6.471	6.30	3.99	72823	7313	·100	Broken.
15	6.471	5.24	4.17	103622	6525	·063	
16	6.471	5.05	4.25	82261	6674	·081	
17	7.549	6.21	4.25	87443	7022	·080	
18	8.628	6.21	5.32	82332	9607	·116	Broken.
19	8.628	6.21	5.15	103863	8993	·087	
20	8.628	7.37	6.21	137966	15584	·113	
21	8.628	7.45	6.21	137866	15764	·114	
					Mean . . .	·996	

It thus appears that the force required to break a timber in the direction of its length, is about ten times that which would break it if applied transversely at the middle; from which I infer that the strain in the direction of the gate produced by the pressure of the opposite one, is equal to an additional strain of one-tenth applied transversely.

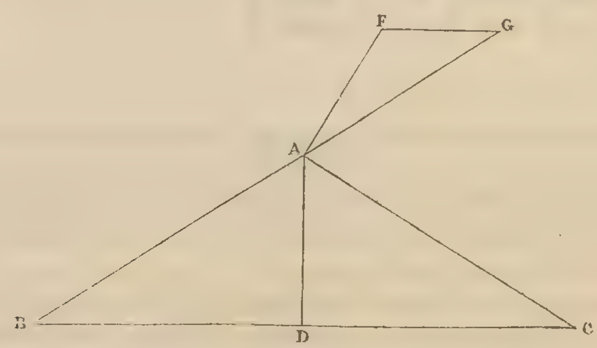
A difference exists in the comparison made in the preceding Table and in the case of lock gates, which it is necessary to make some remarks upon;

viz., that a lock gate has a transverse pressure acting in addition to that produced by the other gate, so that the end pressure is exerted upon it after it is already deflected by a transverse strain, which is of course not the case in the comparison made in the Table. How far this may affect the question, or how much greater effect the compressive force may have in consequence of the beam being already deflected, it is very difficult to determine, but from an examination of the subject, I am induced to think that the deflection is so small as very slightly to increase the effect of the end pressure.

The amount of the effect will of course depend upon the degree of deflection the beam has sustained from the transverse pressure, and if it amounted to a quantity exceeding one-twentieth of the length, (which would make the lever by which the end pressure acted exceed one-tenth of that by which the transverse strain acted,) a greater effect than one-tenth would be produced; but as the ordinary load which timber is expected to sustain, does not produce at the utmost a deflection exceeding one-hundredth part of the length, I cannot conceive the transverse strain above named materially to alter the comparison, and I have accordingly, in the following investigation, assumed one-tenth as the amount of additional strain produced by the end pressure of the opposite gate.

It now becomes necessary to get an expression for the amount of the strains above mentioned at any angle of salience, which is arrived at in the following manner:—

Let AB, AC, represent the two gates, meeting at the point A; draw the line AD from the point A perpendicular to BC, and let BD, which represents half the breadth of the lock, $= l$, also



let the pressure of water upon the length l of the gate be indicated by w and the angle ABD $= \phi$.

Then the length of the AB and any angle ϕ will be expressed by . $l \sec\phi$

and the pressure upon it by . . . . $w \sec\phi$

The transverse strain produced by this pressure on the centre of the beam at the same angle, will be . . . . $\frac{1}{2}w \sec\phi$

It now remains to find the amount of compression in the direction of the gate, produced by the opposite gate.

Let AF represent the force or tendency of the gate AC to turn upon the point C, which is of course equal to half the weight upon the gate AC,

$$\text{or} = \tfrac{1}{2}w \sec\phi$$

The force may be resolved into AG, FG, the one GF is supported by an equal and opposite force in the gate AB, and the other will represent the force in the direction of the gate, the expression for which may be found as follows;

$$\text{as sine} \angle \text{AGF} : \text{AF} :: \text{sine} \angle \text{AFG} : \text{AG}$$

$$\text{or sine}\phi : \tfrac{1}{2}w \sec\phi :: \cos\phi : \tfrac{1}{2}w \sec\phi \frac{\cos\phi}{\text{sine}\phi} = \tfrac{1}{2}\text{cosec}\phi$$

The whole amount of transverse strain at any angle ϕ will therefore be represented by the expression,

$$\tfrac{1}{2}w \sec\phi + \tfrac{1}{20}w \text{ cosec}\phi$$

from which we may readily obtain the angle at which the strain is a minimum as follows;—

$$\begin{aligned}
&\sec\phi + \tfrac{1}{10} \text{cosec}\phi = \text{min} \\
&\text{or } \tan\phi \sec\phi \, d\phi - \tfrac{1}{10} \cot\phi \, \text{cosec}\phi \, d\phi = 0 \\
&\text{whence } \tan^2\phi = \tfrac{1}{10} \text{cotan}\phi \\
&\text{and } \tan^3\phi = \tfrac{1}{10} \\
&\tan\phi = \sqrt[3]{\tfrac{1}{10}} = \tfrac{1}{10}\sqrt[3]{100} = .4641 = \tan \angle 24^\circ 54'
\end{aligned}$$

The salient angle of a pair of oak gates, when the strain is a minimum, is therefore 24° 54′.

In the question of the best angle for lock-gates, it becomes necessary to consider that the length of the gate also varies as the secant of the angle ϕ. The angle 24° 54′ is therefore not that at which, with a given section of timber, the greatest strength will be obtained; for although the strain is the least at this angle, yet the gates, by their greater length, are less able to resist it than at some

intermediate angle, when the strain is slightly increased. The expression now becomes

$$\sec^2\phi + \tfrac{1}{10}\sec\phi\,\operatorname{cosec}\phi = \min$$

$$2\sec^2\phi\,\tan\phi\,d\phi + \tfrac{1}{10}(\tan\phi\,\sec\phi\,\operatorname{cosec}\phi - \cot\phi\,\operatorname{cosec}\phi\,\sec\phi) = 0$$

$$2\sec\phi\,\tan\phi + \tfrac{1}{10}\tan\phi\,\operatorname{cosec}\phi = \tfrac{1}{10}\operatorname{cotan}\phi\,\operatorname{cosec}\phi$$

$$2\sec\phi\,\tan^2\phi + \tfrac{1}{10}\tan^2\phi\,\operatorname{cosec}\phi = \tfrac{1}{10}\operatorname{cosec}\phi$$

from which the cubic equation,

$$\tan^3\phi + \tfrac{1}{20}\tan^2\phi = \tfrac{1}{20}.$$

This, being reduced, makes the tan. = .25701, or the angle 19° 25′, at which a pair of lock-gates should be situated, so as to have the greatest strength with a given section of timber.

Having obtained, in a manner I hope satisfactory, the angle of greatest strength for gates of straight timber, I conclude this part of my paper with a Table of the necessary dimensions of oak timber for lock-gates, varying from 6 to 20 feet in length, and from 8 to 20 feet in depth, which I believe are the limits of the dimensions of gates of this construction.

The first column in each division of the Table gives the amount of transverse strain produced by the pressure of water upon three feet depth of surface, at an angle of 19° 25′; and the second column the dimensions of square oak timber necessary to bear three times that strain.

TABLE II.

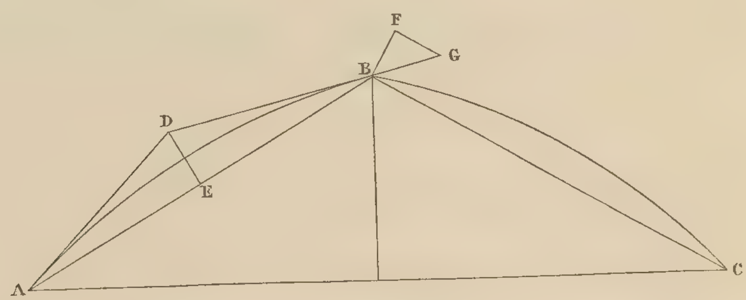
Length of Gate.	6 FEET DEEP.		8 FEET DEEP.		10 FEET DEEP.		12 FEET DEEP.		14 FEET DEEP.		16 FEET DEEP.		18 FEET DEEP.		20 FEET DEEP.	
	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.	Strain produced by the pressure upon 3 feet surface.	Dimensions of Square Timber necessary to bear three times that strain.
FEET.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.	TONS.	INCHES.
5	1.601	4.86	2.134	5.35	2.668	5.77	3.202	6.13	3.735	6.45	4.269	6.74	4.803	7.01	5.336	7.26
6	1.921	5.49	2.561	6.05	3.201	6.52	3.842	6.92	4.482	7.29	5.123	7.62	5.763	7.93	6.403	8.21
7	2.241	6.09	2.987	6.70	3.735	7.22	4.483	7.67	5.229	8.07	5.976	8.45	6.724	8.78	7.470	9.10
8	2.561	6.66	3.414	7.32	4.268	7.89	5.123	8.39	5.976	8.83	6.831	9.23	7.685	9.60	8.538	9.94
9	2.882	7.20	3.841	7.92	4.802	8.54	5.763	9.07	6.723	9.55	7.684	9.98	8.645	10.38	9.600	10.75
10	3.202	7.72	4.268	8.50	5.336	9.16	6.404	9.73	7.470	10.24	8.538	10.71	9.606	11.14	10.672	11.54
11	3.522	8.23	4.695	9.06	5.869	9.76	7.044	10.37	8.217	10.92	9.392	11.41	10.566	11.87	11.739	12.30
12	3.842	8.72	5.122	9.60	6.402	10.34	7.684	10.98	8.964	11.57	10.246	12.10	11.526	12.58	12.806	13.03
13	4.162	9.20	5.548	10.12	6.937	10.90	8.325	11.59	9.711	12.20	11.099	12.76	12.488	13.27	13.874	13.74
14	4.482	9.67	5.974	10.64	7.470	11.46	8.966	12.18	10.458	12.82	11.952	13.40	13.448	13.94	14.940	14.44
15	4.803	10.12	6.402	11.14	8.064	12.00	9.606	12.75	11.205	13.42	12.807	14.03	14.409	14.55	16.008	15.12
16	5.122	10.56	6.828	11.63	8.536	12.53	10.246	13.31	11.952	14.01	13.662	14.65	15.370	15.24	17.076	15.78
17	5.443	11.00	7.255	12.11	9.071	13.05	10.887	13.86	12.699	14.60	14.514	15.26	16.330	15.86	18.142	16.43
18	5.763	11.43	7.683	12.58	9.603	13.55	11.526	14.40	13.446	15.16	15.369	15.85	17.289	16.48	19.209	17.07
19	6.083	11.85	8.109	13.04	10.138	14.04	12.167	14.93	14.195	15.72	16.222	16.43	18.251	17.09	20.277	17.70
20	6.404	12.26	8.536	13.49	10.672	14.54	12.808	15.45	14.940	16.26	17.076	17.00	19.212	17.68	21.344	18.31

In making use of the above Table, for obtaining the necessary dimensions of the lower timbers, it has to be considered that a great support is afforded by the sill of the Gate, which will of course permit with safety the use of less timber than the Table will give. The influence of this support cannot, however, extend beyond the second timber from the bottom, as the deflection of the planking will allow the whole of the pressure to be effective.

Curved Lock Gates.

In locks of large dimensions in this country, a curved figure is given to the gates, so that when united they resemble a Gothic arch; this figure, by giving greater strength, permits a reduction to be made in the dimensions of the timber, and the gates are thereby rendered lighter, and more readily movable. The degree of curvature which will give the greatest strength, and the necessary dimensions of the timber in different sized locks, are of course points of considerable importance, not only on the score of economy, but from the greater degree of lightness that may be thus obtained; the opening and shutting can be performed with greater ease, and consequently a greater number of ships can be permitted to pass in a given time.

In order to estimate the degree of curvature which will give the greatest strength, it is first necessary to consider the nature and amount of the strains to which the Gothic shape gives rise, we may then perceive what variations, with respect to the degree of curvature and amount of salience, will tend to increase the strength, or vice versâ.



Let AB, BC represent two gates meeting in the point B, and let the angle of salience, BAC, be equal to ϕ, also the angle DBE of a tangent to the curve of the gate, with the cord BA $= \theta$, and the pressure of water upon each gate $= w$. The gate AB, being loaded equally all over, will exert a pressure in the direction of the tangent, to the extremity of the gate, which will be represented by the line DB, (the perpendicular DE being equal to $\frac{1}{2}w$,) or equal $\frac{1}{2}w \operatorname{cosec}\theta$.

This force is partly resisted by the compressive force of the opposite gate, which now, instead of adding to the transverse strain, as in the straight gates, is the means of diminishing it in proportion as it counteracts or destroys the

tangential force DB. In order therefore to estimate the amount of strain, it becomes necessary to get an expression for this force, which may be done as follows. Let BF represent the force acting at right angles to the extremity of the gate BC, tending to turn it upon the point C, which is of course equal to half the pressure of water. Resolving this into the direction of the tangent of the curve AB, by drawing FG parallel to BC, and producing DB, we obtain the line BG, which represents the compressive force of the gate BC in the direction of the tangent DB, and which is equal $\frac{1}{2}w$ cosec $(2\phi-\theta)$.

As the diminution of strain owing to this force is, in proportion it destroys the tangential force DB, the amount of the transverse strain at any angle, ϕ and θ may be found by the following proportion:

$$\tfrac{1}{2}w \operatorname{cosec}\theta : \tfrac{1}{2}w\,\{\operatorname{cosec}\theta-\operatorname{cosec}(2\phi-\theta)\} :: \tfrac{1}{2}w : x$$

$$\text{Or, } x=\frac{\frac{1}{2}w\,\{\operatorname{cosec}\theta-\operatorname{cosec}\,(2\phi-\theta)\}}{\operatorname{cosec}\theta}=\tfrac{1}{2}w\left\{1-\frac{\operatorname{cosec}(2\phi-\theta)}{\operatorname{cosec}\theta}\right\}$$

$$=\tfrac{1}{2}w\left\{1-\frac{\sin\theta}{\sin(2\phi-\theta)}\right\}$$

which is the true expression of the transverse strain or weight applied transversely in the middle of the length, which would have equal effect in breaking the timber.

It will at once be seen that when the gates united form a complete arch, that is, when the angles ϕ and θ become equal, the expression vanishes, the tangential force being then resisted by an equal compressive force in the opposite gate.

In this position, therefore, if the curve was mathematically true, the strain perfectly equal and regular, and the material also of an uniform density, the loading the arch would have no other effect than that of direct compression in the direction of the fibres, a description of strain which timber possesses great power to resist, as appears from the experiments of Girard. In practice this cannot, however, take place; the curve can neither be perfectly true nor the density of the material uniform, either of which defects would lead to a transverse strain, which, if sufficient weight was put on, would ultimately destroy the gate. In the former case, the flatter parts of the curve would naturally have a transverse strain upon the bottom fibres, from the abutments or terminations of it not being resisted with an equal degree of compressive force; the fibres would in consequence in some measure yield, and the relative position of the gates at the point of meeting would be changed, so as not to touch equally

throughout; an increased compression would be brought upon particular fibres, which must of course yield, and the evil would continue to increase until fracture ultimately took place. In a similar manner, an irregular density of the material, by causing a yielding in some parts more than others, would bring on a change of shape which would ultimately produce the same results.

It therefore appears that in either case the cause which ultimately leads to fracture is the transverse strain produced from the irregularity of the curve, brought on by circumstances which cannot be controlled. Hence the nearer the curve can be preserved in the true figure of an arc of a circle, the greater the strength of the gates.

It has however to be considered that the arch is not composed of one complete timber, but that the fibres are disunited at the point of meeting, and consequently if that part from any cause should become flattened there are no fibres to resist the transverse strain thus produced; and as the flattening of this part of the arch is an effect which might probably arise from any yielding of the abutments, or wear of the heel posts in the hollow quoin, this would evidently be the weakest part of the curve. It therefore becomes necessary to deviate in a small degree from the true curve of the arch, by giving the gates greater length, and causing them to meet at a point a short distance from the curve, or in fact rendering them slightly Gothic; but as the security to the point is obtained at the expense of a constant transverse strain upon each of the gates, the deviation from the true arched figure should be as little as possible, consistently with the object in view, and by no means so great as is commonly employed in lock gates: I should think a deviation of one foot or eighteen inches quite sufficient for the purpose of locks of from forty to fifty feet wide.

General Remarks.

It was my intention to have concluded the preceding part of the article with a Table of the requisite dimensions of timber for gates of different sizes, both of the curves commonly employed, and of those which I should recommend; I find, however, that these calculations would require a greater length of time than I can at present devote to the subject, and I therefore conclude with a few general remarks on the results arrived at.

In the first place, with respect to the proper angle of straight gates, this being a subject naturally calculated to excite the propensities of the mathema-

tician to set his maxima and minima to work, a great number of solutions to the problem have been given; but I must remark, with every respect for that useful class of men, that they are frequently too anxious to commence investigations without sufficient data, and consequently arrive at results totally incorrect, which has certainly been the case in those investigations I have had an opportunity of examining on the subject.

It seems to me perfectly impossible to arrive at correct results, without first ascertaining the amount of transverse strain produced by the end pressure, which does not seem to have been done before; but having obtained this from Girard's experiments to be one-tenth of the effect of an equal weight in the middle of the length, I have little doubt that the angle 19° 25′ would be found, by experiments, to be very nearly that in which the greatest strength would be obtained with a given quantity of timber.

The angle commonly adopted in this country, is considerably more than 19° 25′, amounting generally to between 30 and 40 degrees, which is said to be preferred from the direction of the thrust being met by a larger quantity of brickwork. I cannot, however, conceive this to be a matter of much importance, particularly as there are locks on the continent, of large dimensions, where the angle is considerably less, which have stood perfectly well. The angle of the celebrated sea-lock of Muyden is only 16° 30′, and the ancient lock of Sparendam, which was built in 1568, and has stood many storms without injury, has a sally of not more than one-sixteenth:—the angle ought certainly to be in some measure guided by the circumstances in which the gate is placed; at the same time, I consider the angle commonly made use of in England, to be decidedly larger than necessary, and a useless weight of material employed, which increases one of the evils of canal navigation,—the time consumed in passing the locks.

The employment of curved timber is undoubtedly advantageous, but its application is evidently made upon no fixed principles, as may be seen from the differences of the curves which have been adopted; some being so great as to very nearly approach the figure I have pointed out as the best, while others are so exceedingly flat that they possess little advantage over the straight gate.

To illustrate these differences in wooden gates, I have represented, in the accompanying drawing, the curves employed in the gates of the St. Katharine's, London, and West India Docks. The dimensions are as follows:—

ST. KATHARINE'S DOCKS.

Width of the lock . . . . 45 feet.
Projection 11
Radius of the gate 117

Consequently the angle $\phi = 29^\circ\ 16'$, and $\theta = 6^\circ\ 8'$.

LONDON DOCKS.

Width of the lock . . . . 40 feet.
Projection 9
Radius of the gate 50

Angle $\phi = 23^\circ\ 35'$, and $\theta = 13^\circ\ 54'$.

WEST INDIA DOCKS.

Width of the lock . . . . 45 feet.
Projection 10
Radius of the gate 120

Angle $\phi = 26^\circ\ 24'$, and $\theta = 5^\circ\ 53'$.

With the aid of the preceding formulæ I have calculated the amount of transverse strain in each case, (half the pressure of water upon one gate being unity,) and the same, if they were of straight timber, having an equal salient angle. These formulæ are arranged in the following Table.

In order to make the comparison of the straight and curved gate more direct, there is also added a column of the amount of transverse strain on the latter, that on the straight gate being unity.

The fourth column illustrates the reduction of the dimensions of square timber which may be permitted owing to the diminished strain.

TABLE III.

Gate.	Transverse strain, $\frac{1}{2}w$ being unity.	Transverse strain of straight timber having the same salient angle, $\frac{1}{2}w$ being unity.	Transverse strain, that on the straight gate being unity.	Dimensions of timber having equal strength, that on the straight gate being unity.
At St. Katharine's Docks .	·86	1.178	·73	·900
London Docks . . .	·56	1.229	·45	·766
West India Docks . .	·86	1.201	·72	·896

It thus appears that a considerable advantage is gained in each case from the curvature, but that in the London Docks, from the radius being less, and the two gates in consequence approaching nearer the curve of a complete arch, the advantage is much greater, and the transverse strain in consequence reduced to less than half that of straight gates having the same salient angle.

The difficulty of obtaining timber of sufficient curvature has been urged as a reason for the flatness of the curves employed in wooden gates; this is certainly a consideration which must be attended to, but as similar curves are employed when the material made use of is cast iron, I cannot conceive this to be a point which has materially influenced the choice of the figure.

In the accompanying drawing (Plate XIII.) are given the curves of the gates of the Caledonian Canal, Dundee Docks, and Sheerness Basin, which are of cast iron: they will be found to differ very materially from each other, being in one instance nearly as flat as in the West India and St. Katharine's Docks.

The following are the dimensions:—

CALEDONIAN CANAL.

Width of the lock	40 feet.
Amount of projection	10
Radius of curvature	75

Angle of sally $\varphi = 30^\circ$, and $\theta = 8^\circ\ 3'$.

DUNDEE DRY DOCKS.

Width of entrance	40 feet.
Amount of projection	7 feet 6 inches.
Radius of curvature	67 feet.

Angle of sally $\varphi = 22^\circ\ 2'$, and $\theta = 9^\circ\ 12'$.

SHEERNESS BASIN.

Width of entrance	58 feet.
Amount of projection	12 feet 6 inches.
Radius of curvature	55 feet.

Angle $\varphi = 24^\circ\ 5'$, and $\theta = 16^\circ\ 55'$.

To make a comparison of these curves, I have calculated a Table, as in the case of the wooden gates, containing the amount of the transverse strain which straight gates would have under similar circumstances.

The same formula is employed for this purpose as for the wooden gates, which may not be strictly true with cast iron; but I should not conceive the difference to be sufficient to affect materially the comparison.

TABLE IV.

Gate.	Transverse strain, half the pressure of water being unity.	Transverse strain of a straight gate, with the same salient angle.	Transverse strain, that of the straight gate being unity.	Dimension of iron of similar section with the straight gate, that of the latter being unity.
At Caledonian Canal . .	·82	1.173	·700	·887
Dundee Docks . . .	·72	1.247	·58	·834
Sheerness Basin . . .	·44	1.215	·35	·704

It thus appears that in the gates of the Caledonian Canal the transverse strain is nearly as great as in the West India and St. Katharine's Docks. In those of the Dundee Docks and Sheerness Basin, a considerable improvement is made, particularly in the latter, where the strain amounts to little more than one-third of that which straight gates would have in the same situation; but I conceive that by slightly diminishing the salient angle, and increasing the curvature of the gates, the advantage might be carried still further,—the same strength produced by less weight of material, and a lightness given which would greatly facilitate the passing and repassing of vessels.

V. *On the Hot Air Blast.* *By Mr.* J. B. NEILSON, *Cor.Mem.Inst.C.E.* *Communicated in a Letter to the late President,* THOMAS TELFORD, *Esq.* *

I FEEL much pleasure in being able to comply with your request in mentioning to you what I conceive to be the nature of the advantages likely to be derived by the Iron Trade, and the country generally, from my invention of the Hot Blast, and at the same time, I shall very willingly state the circumstances, agreeably to your request, which, in the first instance, led me to direct my attention to the improvement of the process of iron-making.

About seven years ago, an iron-maker, well known in this neighbourhood, asked me if I thought it possible to purify the air blown into blast furnaces, in a manner similar to that in which carburetted hydrogen gas is purified; and from this gentleman's conversation, I perceived that he imagined the presence of sulphur in the air to be the cause of blast furnaces working irregularly, and making bad iron in the summer months. Subsequently to this conversation, which had in some measure directed my thoughts to the subject of blast furnaces, I received information that one of the Muirkirk iron furnaces, situated at a considerable distance from the engine, did not work so well as the others; which led me to conjecture that the friction of the air, in passing along the pipe, prevented an equal volume of the air getting to the distant furnace, as to the one which was situated close by the engine. I at once came to the conclusion that by heating the air at the distant furnace, I should increase its volume in the ratio of the known law, that air and gases expand as 448 + temperature.

Example.—If 1000 cubic feet, say at 50° of Fahrenheit, were pressed by the engine in a given time, and heated to 600° of Fahrenheit, it would then be increased in volume to 2104·4, and so on for every thousand feet that would be blown into the furnace. In prosecuting the experiments which this idea suggested, circumstances however became apparent to me, which induced the belief on my part, that heating the air introduced for supporting combustion into

* Although the application of heated air has been extended, and the subject treated more at large since this paper was written, the detail of the discovery from Mr. Neilson to the late President, cannot fail to be interesting. In a future volume, the Council trust to be able to add a further communication from that gentleman on the subject.

air furnaces, materially increased its efficiency in this respect; and with the view of putting my suspicions on this point to the test, I instituted the following experiments.

To the nozzle of a pair of common smith's bellows, I attached a cast iron vessel heated from beneath, in the manner of a retort for generating gas, and to this vessel, the blow-pipe by which the forge or furnace was blown, was also attached. The air from the bellows having thus to pass through the heated vessel above mentioned, was consequently heated to a high temperature before it entered the forge fire, and the result produced, in increasing the intensity of the heat in the furnace, was far beyond my expectation, and so evident as to make apparent to me the fallacy of the generally received opinion, that the coldness of the air of the atmosphere in the winter months, was the cause of the best iron being then produced.

In overthrowing the old theory, I had however established new principles and facts in the process of iron-making, and by the advice and assistance of Charles M'Intosh, Esq., of Crossbasket, I applied for and obtained a patent, as the reward of my discovery and improvements.

Experiments on the large scale to reduce iron ore in a founder's cupola, were forthwith commenced at the Clyde Iron Works, belonging to Colin Dunlop, Esq., which experiments were completely successful, and in consequence, the invention was immediately adopted at the Calder Iron Works, the property of William Dixon, Esq.; where the blast being made to pass through two retorts placed on each side of one of the large furnaces, before entering the furnace, effected an instantaneous change, both in the quantity and quality of iron produced, and a considerable saving of fuel.

The whole of the furnaces at Calder and Clyde Iron Works were in consequence immediately filled up on the principle of the Hot Blast, and its use at these works continues to be attended with the utmost success; it has also been adopted at Wilsontown and Gartshirrie Iron Works in Scotland, and at several works in England and France, in which latter country I have also obtained a patent.

The air as at first raised to 250° of Fahrenheit, produced a saving of three-sevenths in every ton of pig-iron made, and the heating apparatus having since been enlarged, so as to increase the temperature of the blast to 600° Fahrenheit and upwards, a proportional saving of fuel is effected; and an immense additional saving is also acquired by the use of raw coal instead of coke, which may

now be adopted. By thus increasing the heat of the blast, the whole waste incurred in burning the coal into coke is avoided in the process of iron-making.

By the use of this invention, with three-sevenths of the fuel which he formerly employed in the cold air process, the iron-maker is now enabled to make one-third more iron of a superior quality.

Were the Hot Blast generally adopted, the saving to the country in the article of coal, would be immense. In Britain, about 700,000 tons of iron are made annually, of which 50,000 tons only are produced in Scotland; on these 50,000 tons, my invention would save in the process of manufacture, 200,000 tons of coal annually. In England, the saving would be in proportion to the strength and quality of the coal, and cannot be computed at less than 1,520,000 tons annually; and taking the price of coals at the low rate of four shillings per ton, a yearly saving of £296,000 sterling would be effected.

Nor are the advantages of this invention solely confined to iron-making: by its use the founder can cast into roods an equal quantity of iron, in much less time, and with a saving of nearly half the fuel employed in the cold air process; and the blacksmith can produce in the same time one-third more work, with much less fuel than he formerly required.

In all the processes of metallurgical science, it will be of the utmost importance in reducing the ores to a metallic state.

VI. *On the Relation between the Temperature and Elastic Force of Steam, when confined in a Boiler containing Water.* *By Mr.* Farey, *M.Inst.C.E.*

This subject has occupied the attention of many able experimenters, and the coincidence of the results which they have attained separately, leaves no doubt of the facts hereinafter stated.

Mr. Watt made experiments in 1764, and repeated them in 1774. Mr. Southern went over them again in 1797 with great accuracy, and formed a theorem for calculating the results; Dr. Robinson and M. Bettancourt also made similar experiments; likewise Mr. Dalton, Mr. Woolf, and Mr. Philip Taylor; also Dr. Ure.

The writer of this communication undertook, several years ago, to compare all the different experiments which had then been made, in order to obtain a standard, and was induced, after a careful examination*, to adopt Mr. Southern's theorem as the most authentic, being found very consistent with itself, and being confirmed, at several points of the scale, by the actual experiments of others, although the complete scales promulgated by some of those others were very discordant, from having been interpolated between the actual experiments by incorrect theorems; and particularly some scales which had been extended by such theorems beyond the range of their actual experiments, were found to be very far from the truth. In consequence, Mr. Southern's scale was made the foundation of all the Writer's computations and statements respecting steam; many of which have since been published.

The principal object of the present communication is, to shew the coincidence between Mr. Southern's scale, and that of a new series of experiments made in Paris, in 1829, by a Committee of the Academy of Sciences, which confirms the standard so completely, as to leave no doubt of its truth.

Another object of the communication is to put on record, in the papers of the Institution, a memorial of the fair claim of our countryman, Mr. Southern, to the merit of priority in accurate determination of this law, in opposition to the

* The mode of examination was that which Mr. Smeaton and Mr. Watt pursued in similar cases, viz., to form curves for representing each scale, the temperature, in degrees of the thermometer, being the ordinates, and the elasticities, in atmospheres, being the abscissæ of the curves.

unfounded assertion of the French author, who has published the new experiments, that the academicians had first established the truth in 1829, and that the previous determinations in England were erroneous*. Mr. Southern's determination is not mentioned in this sweeping condemnation, although it had been republished by Mr. Watt, Dr. Brewster, Dr. Thomson, and in the Writer's Treatise on the Steam Engine, also in that of Mr. Tredgold, and is well known, and very generally adopted, in fact, by the French academicians themselves.

The French experiments were continued up to twenty-four atmospheres; Mr. Southern's went only as far as eight atmospheres; he found the corresponding temperature to be 343·8 degrees of Fahrenheit's thermometer, and the academicians found it to be 341·8 degrees, or just two degrees less. At four atmospheres, Mr. Southern found the temperature 293·9 degrees, and the academicians 293·7. This last is not an accidental coincidence, but an adoption of Mr. Southern's scale, through Mr. Tredgold, though not acknowledged as such.

The French academicians have formed a theorem for calculating the temperatures corresponding to the elasticities, and by means thereof have extended their scale from twenty-four atmospheres upwards; nevertheless, they did not use their own theorem for the most useful part of the scale below four atmospheres, but they adopted a theorem from Mr. Tredgold in lieu of their own.

That theorem was made by Mr. Tredgold, from Mr. Southern's experiments, in lieu of Mr. Southern's own theorem, merely because Mr. Tredgold did not think that a power with a fractional index, viz. 5·13, is likely to represent the law of nature. This induced him to employ a higher power, with 6 for an index; and in consequence, his formulæ did not correspond at all with Mr. Southern's experiment at eight atmospheres, although it did correspond at four atmospheres. The academicians use an index of 5 in their theorem, rendering it very nearly the same in effect as Mr. Southern's.

* The French account of the occasion of making their experiments on the temperatures corresponding to different elasticities of steam, in 1829, contains the following passage:—"Science "did not then possess this knowledge, and engineers appointed to superintend the construction "of steam engines, had no other guidance than some discordant measures upon the temperatures "which correspond to the elasticities between one and eight atmospheres; for higher pressures "there was no result of direct experiments, nor any theory which could supply the deficiency."

It is afterwards stated that only one experiment by Mr. Perkins was obtained in England, and that is shewn to be altogether erroneous; and then, that "Germany was more advanced than England, for the results in question, Mr. Arzberger, at Vienna, having made experiments." but they are also shewn to be inexact.

In adopting this formula from Mr. Tredgold, (who quotes Mr. Southern's experiments, and takes them as his basis,) the French academicians could not have been ignorant of Mr. Southern's determinations, nor of their accuracy; for at eight atmospheres, his experiments and theorem is nearer to their own experiments than Mr. Tredgold's theorem, which they have adopted for that part of their scale which is below four atmospheres, and which theorem gives a result identical with Mr. Southern's theorem and experiments, at two and a half atmospheres, although Mr. Tredgold's becomes very incorrect below boiling, and also above four atmospheres.

Under these circumstances, it was not candid that all mention of Mr. Southern's determinations should have been suppressed, when in fact they are adopted at second hand, and through a less correct version than his own; and when it was found requisite to amend that version, and put it back very near to its original value, the author of that original should have been cited.

In a former report by the Academy in 1825, a Table was given, which is exactly Mr. Southern's numbers, and it would have been only fair, that his standard should have been acknowledged when adopted*. The merit of extending it, by further experiments, up to twenty-four atmospheres, in 1829, and thereby proving Mr. Southern's exactitude, is willingly acknowledged by the Writer of this communication, to be due to the French academicians.

When the temperature due to an elasticity of twenty-four atmospheres is calculated by Mr. Southern's theorem, it gives 438·2 degrees of Fahrenheit's thermometer, whilst the French experiment is 435·6, or only 2·6 degrees less; of this difference, some part is occasioned by the difference in the French and English mode of reckoning what an atmosphere is †. Again, for sixteen atmospheres, Mr. Southern's theorem gives 401·0 degrees, and the French experiment 398·5, or $2\frac{1}{2}$ degrees less. At eight atmospheres, 2 degrees less, as before stated.

* In the account of the experiments of 1829, the former Table of 1825, is mentioned as "having been only presented temporarily, and as having been only deduced from interpolation of "all the experiments which seemed to merit the most confidence, from the ability of the observers, "and from the nature of the methods of observation;" but no mention is made of Mr. Southern, although the numbers are his.

† The French reckon an atmosphere to be equal to a column of mercury $\frac{76}{100}$ of a metre in height, which is only 29·92 inches, and the boiling point of their thermometer is adapted thereto, whereas, since about the commencement of the present century, the English have reckoned it to be 30 inches. This circumstance accounts in some degree for their scale of temperatures differing from Mr. Southern's.

These small differences are less than the inevitable uncertainties of observation in such experiments, and it is to be remarked, that the elasticities were measured by the French academicians by the compression of air included in a manometer, and not by a direct measure of a column of mercury, or a loaded safety valve; whereas Mr. Southern used both those means, and employed very correct thermometers, and therefore his scale is of as much authenticity as that of the French; and the Writer of this communication does not think it requisite to make any alteration in the standard which he adopted long ago for all his calculations on this subject, and of which many are published in his Treatise on the Steam Engine, where the subject is fully explained; and it is only necessary to give an extract therefrom, in order to state Mr. Southern's determination of a correct scale.

"From the comparison of a great number of his experiments, Mr. Southern invented a method of calculating the elasticity of steam at different temperatures, when saturated with water; his method is embodied in the following rule, which will give results very nearly corresponding with the experiments.

"To find the elasticity of steam of any given temperature, that temperature being expressed in degrees of Fahrenheit's thermometer, and the elasticity being expressed by the height, in inches, of the column of mercury that the steam will support.

"Rule.—To the given temperature in degrees of Fahrenheit, add the constant temperature 51·3 degrees, and take out the logarithm of the augmented temperature from a table of logarithms; multiply that logarithm by the constant number 5·13, and from the product (which is a logarithm) deduct the constant logarithm 10·94123; then by the table of logarithms find the number corresponding to the remainder, (which is also a logarithm,) and that number is one tenth of an inch less than the height required; therefore, by adding one tenth of an inch to the said number, we have the proper height, in inches, of the column of mercury that the steam will support *.

"Example.—What is the elasticity of steam at 212 degrees of temperature? 212 deg + 51·3 deg = 263·3 deg; the logarithm of that number is 2·42045, which

* "The effect of multiplying the logarithm by 5·13, is to raise the 5·13th power of the temperature, when augmented as above, and then the effect of deducting the constant logarithm 10·94123, is to divide the high power previously raised, by a very large number, viz. (87 344 000 000) eighty-seven thousand three hundred and forty-four millions. The quotient resulting from this division of the high power, with the constant addition of one tenth of an inch, is the required elasticity in inches of mercury."

$\times 5 \cdot 13 = 12 \cdot 4169$; from this logarithm deduct the constant logarithm 10·94123, and the remainder is 1·47567; the number corresponding to this logarithm is 29·9 inches, and, adding one tenth of an inch thereto, we have thirty inches of mercury for the required elasticity.

"The rule may be used conversely to find the temperature of steam of any given elasticity thus. Deduct one-tenth of an inch from the height in inches of the column of mercury; take out the logarithm of the diminished height, and add to it the constant logarithm 10·94123; then divide the sum of these logarithms by the constant number 5·13; and find by the Table of logarithms, the number which corresponds to the quotient: that number is 51·3 degrees more than the required temperature; therefore deduct 51·3 from the said number, and the remainder is the proper temperature in degrees of Fahrenheit.

"Example: What is the temperature of steam of an elasticity of 120 inches of mercury? 120 inc. $-$ ·1 $=$ 119·9 inc. The logarithm of that number is 2·07882, to which add the constant logarithm 10·94123 $=$ 13·02005, for the sum of the logarithms, which being divided by 5·13 constant number, gives 2·53802 quotient. The number corresponding to that logarithm is 345·2 degrees, from which deduct the constant temperature 51·3 degrees, and we have 293·9 degrees for the required temperature.

" The following Table has been calculated by Mr. Southern's theorem.

" Temperature. Degrees of Fahrenheit.	Elasticity. Column of mercury; inches.	
32 freezing.	0·18	These numbers are nearly identical with experiments.
42	0·25	
52	0·35	
62	0·50	
72	0·71	
82	1·01	
92	1·42	
102	1·97	
112	2·68	
122	3·60	
132	4·76	
142	6·22	
152	8·03	
162	10·25	
172	12·94	
182	16·17	
192	20·04	
202	24·61	
212 boiling.	30·00	

These numbers are from the French Academicians.	Temperature. Degrees of Fahrenheit.	Elasticity. Column of mercury; inches.
212	212 =1 Atmos.	30·00
	222	36·32
	232	43·60
	242	52·20
250·5	250·2=2 Atmos.	60·00
	252	61·90
	262	73·00
	272	85·80
275·2	275 =3 Atmos.	90·00
	282	100·30
	292	116·70
293·7	293·9=4 Atmos.	120·00
	302	135·20
307·5	309·2=5 Atmos.	150·00
	312	156·00
	322	179·30
320·4	322·3=6 Atmos.	180·00
	332	205·40
331·7	333·7=7 Atmos.	210·00
	342	234·40
341·8	343·8=8 Atmos.	240·00"

Treatise on the Steam Engine, Vol. I. p. 72.

It is presumed that it has now been shewn that English engineers have, for more than 30 years past, been in possession of a standard scale, which is very accurate, and also of a theorem whereby the temperatures corresponding to elasticities, exceeding 8 atmospheres, may be correctly represented, notwithstanding assertions to the contrary.

The complete scale laid down by the French Academicians is as follows.

Elasticities.	Atmospheres.	Temperatures in Degrees Fahrenheit.		
Thus far was calculated by Mr. Tredgold's rule, which proceeds by the 6th power.	1	212·0	212·0	These numbers are calculated according to Mr. Southern's rule, which proceeds by the 5·13th power.
	$1\frac{1}{2}$	234·0	233·7	
	2	250·5	250·2	
	$2\frac{1}{2}$	263·8	263·8	
	3	275·2	275·0	
	$3\frac{1}{2}$	285·1	285·0	
	4	293·7	293·9	
These were calculated by the French Academicians' rule, which proceeds according to the 5th power.	$4\frac{1}{2}$	300·3	301·9	
	5	307·5	309·2	
	$5\frac{1}{2}$	314·2	316·0	
	6	320·4	322·3	
	$6\frac{1}{2}$	326·3	328·1	
	7	331·7	333·7	
	$7\frac{1}{2}$	336·9	338·9	
	8	341·8	343·8	
	9	350·8		
	10	358·9		
	11	366·8		
	12	374·0	376·3	
	13	330·7		
	14	386·9		
	15	392·9		
	16	398·5	401·0	
	17	403·8		
	18	408·9		
	19	413·8		
	20	418·5	421·1	
	21	423·0		
	22	427·3		
	23	431·4		
	24	435·6	438·2	

NOTE. At 4 atmospheres this complete scale changes its law of progression all at once, from the 6th power to the 5th power, which cannot be correct in principle. Neither the 6th power nor the 5th will give correct results in the lower part of the scale, between boiling and freezing, nor in the higher part of the scale. But Mr. Southern's fractional power 5·13, applies without change throughout the whole range, from freezing up to the temperature of melting tin.

By examining the French scale, it appears to correspond with Mr. Southern's at 4 atmospheres within $\frac{2}{10}$ of a degree, but in advancing only to $4\frac{1}{2}$ atmo-

spheres, it falls short $1\frac{6}{10}$ degrees therefrom, and yet, up at 24 atmospheres, the deficiency is but $2\frac{6}{10}$ degrees.

The French theorem is virtually to the same effect as that of Mr. Southern, for the logarithm of the elasticity in atmospheres is divided by 5 (instead of 5·13) in order to extract the 5th root, from which root unity, or 1, is to be deducted, and the remainder divided by the constant decimal ·7153, the quotient expresses the increase of temperature above boiling, in terms of the interval between freezing and boiling, that is, the said quotient expresses what fractional portion of 180 degrees of Fahrenheit, the temperature is above the boiling point.

This is by no means a convenient rule, and does not apply without modification to temperatures below boiling, which Mr. Southern's does most accurately. The French rule, if modified, becomes inaccurate.

The only question as to the law of progression in the French rule being better than that of Mr. Southern's, is whether the 5·13 power is more authentic than the 5th power. Now the Academicians found Mr. Tredgold's rule, which proceeds by the 6th power, did better than their own, between one and four atmospheres, but it will not correspond either at lower or higher parts of the scale, whilst Mr. Southern's corresponds accurately below, and very nearly throughout.

Mr. Southern's theorem is preferable to any other for calculations concerning the heights of mountains, according to observations of the temperatures at which water is found to boil at their summits and at their bases.

On considering all these circumstances, we shall find good reasons for adhering to Mr. Southern's theorem, because it is unquestionably accurate in all the lower part of the scale below boiling, and also above the same, as far as experiments can be made with certainty; and the new experiments of the academicians prove, that at very high parts of the scale, it cannot be far from the truth; but as there is no certainty in the exactitude of either temperatures or elasticities, when so great as 438 degrees and 24 atmospheres, it is not advisable to adopt a new law of progression for the sake of reconciling differences of $2\frac{1}{2}$ degrees from uncertain observations, when that new law will not correspond so well as the established law, with very certain and unquestionable observations.

67, Guildford Street, Russell Square.
1 May, 1833.

P.S. It would be useful information, if some of the junior members, who have leisure, would undertake to calculate the temperatures according to Mr. Southern's rule, for every half atmosphere between 8 atmospheres and 24 atmospheres, now that the French experiments have shewn that his rule will apply to such an extent with very probable accuracy.

VII. *On Ventilating and Lighting Tunnels, particularly in reference to the one on the Leeds and Selby Railway. By J. Walker, Esq., F.R.S. L. and E., President Inst. C.E.*

The want of ventilation and light seems the greatest objection to tunnels on railways and canals. An attempt is making to remedy both these evils in the tunnel now (1832) forming on the Leeds and Selby Railway, near Leeds, by a plan which is simple, not attended with much expense, and likely to be at least partially successful. A short description will suffice to make it understood.

The tunnel is nearly half a mile long; the greatest depth from the surface about 80 feet. As three shafts were required for raising the excavation during the progress of the work, it occurred to me, that by placing them at nearly equal distances, and walling them in a permanent manner, they might be left open to the surface afterwards. A strong elliptical casting, about 8 feet long and 5 feet wide, has therefore been built in the arch of the tunnel, and over this a circular shaft or well, 10 feet diameter, raised in strong brickwork. If it be found expedient to cover the well as a protection from the rain, it may be done with glass, raised on columns of such height as to admit a free circulation of air between the surface of the ground and the roof.

So much for ventilation. But as the light afforded by the shafts is confined to the space immediately below them, the desideratum is to throw it along the tunnel, and I think this may be done so as to give a useful light by means of plane reflectors of tinned iron placed on the ground between the two lines of railway, at such an angle as to reflect the light where it will be most useful. The idea was suggested by the rum vaults in the West India Docks, where the marks on the casks are ascertained by catching the faint light from the windows upon a small piece of tin plate, and throwing it on the casks. Those who have seen this done have generally been surprised at the useful effect produced; but in the case of the tunnel, the light coming directly down the shaft is more powerful, and the effect of the experiments I have made has much exceeded my expectations. I shall take care that the results of any future observations be communicated to the Institution.

P.S.—In compliance with the promise given in the preceding paper, I have procured from Mr. George Smith, the resident engineer on the Leeds and Selby

Railway, the annexed observations on the subject containing the result of his recent experience. Though they do not in all respects realize the expectations I had formed from the first experiments which were made before the tunnel was completed, or the railway formed, I may remark, that while the shafts seem to be very serviceable for ventilation, the light they supply is useful to those whose duties require them to pass through the tunnel on foot or unaccompanied with an engine. Mr. Smith's remarks are dated Dec. 1835, and are as follows:—

"At the present period when there are so many railways in progress and in " contemplation, many of them with tunnels of considerable length, the following " observations on the effects of the Locomotive Engines, working in the tunnel of " the Leeds and Selby Railway, may be interesting to those who have not the " opportunity of witnessing those effects daily and under all circumstances.

"The tunnel of the Leeds and Selby Railway is nearly half a mile in length, " situated at the commencement of that railway at the Leeds end, and has a slight " ascending inclination in going from Leeds. The situation and inclination " cause a considerable difference in the quantity of steam discharged from the " chimneys of two engines travelling in opposite directions.

"The ascending engine labouring at a first start against the inclination, to get " into speed, (which is scarcely done before leaving the tunnel,) causes a great " expenditure of steam, &c., while an engine coming in the opposite direction, " having a clear fire, and every means taken to prevent the generation of steam, " by opening the fire-door and pumping water into the boiler, expends very little, " and that through the safety valve, the smoke from the chimney not being perceptible. It will therefore be necessary to detail the effect of an engine passing " through the tunnel from the Leeds end only.

"The fires of the engines are made up, previous to starting, with coke mixed " with coal, to hasten the ignition of the former; the smoke from the coal is of " course mixed with that of the coke and steam, adding to the density of what " escapes from the chimney, and continues to do so for some time, frequently " through the whole length of the tunnel: but notwithstanding this, the tunnel " is generally clear in less than five minutes after; in many cases nearly as soon " as the engine has left it. This of course is governed, in a great measure, by the " force and direction of the wind. In foggy weather there being little or no wind, " the smoke from the coal is left after the steam is condensed, and forms itself into

" a cloud which sails slowly along the roof, travelling at the rate of from two to " three miles per hour; a great part of it ascends the shafts, but from the heavy " state of the atmosphere, a considerable portion passes them and discharges itself " at one end of the tunnel. It should here be mentioned, that the entrances into " the shaft from the tunnel are much contracted, having not more than 5 feet in " the longitudinal, and 8 feet in the transverse direction of the tunnel, and much " of the smoke, &c., passes on each side of the shafts; and in consequence of the " sluggishness of the draught on those days, the lower part of the cloud has not " sufficient time to alter its course up the shafts *.

" Two engines, having coal mixed with the coke in their fire-boxes, left the " Leeds depôt during a very heavy morning, and followed each other quickly " through the tunnel: each left a cloud behind, the one keeping at a considerable " distance from the other. The smoke (the steam appearing to have been con- " densed) seemed to have lost its usual sulphurous smell, and resembled a dense " fog—the denseness appearing greater from the darkness of the tunnel; and such " is the freedom of those clouds from anything unpleasant, that passengers in " close carriages are not aware of having passed through them, which they do " almost instantaneously.

" Passengers are never annoyed with the steam, &c., from the chimneys of the " engines, as it does not descend low enough, except on heavy days, and even " then, the progress of the engines carries them forward before it is so low as to " affect them.

" From the effects described above, it appears evident, that in tunnels situated " only a short distance from the starting-place, it is extremely probable little or " no inconvenience will be felt by the passengers passing through them.

" Previous to the opening of the Leeds and Selby Railway, great doubts were " entertained by many, and among others a celebrated lecturer, as to the fitness " of the atmosphere for respiration, in a tunnel worked by locomotive engines; " now that the incorrectness of that idea is fully proved, as far as regards a " tunnel half a mile long, those doubts are still entertained by many indi- " viduals, as to tunnels of much greater lengths. These doubts will probably " prove as groundless as the former ones, for the following reasons:—

" A considerable quantity of the steam from the engines ascends the shafts at

* This naturally suggests the propriety of having the shafts much larger, probably the same diameter as the width of the tunnel.

" all times; but there is no doubt a large portion is also condensed in the tunnel; " and were there no shafts at all, the steam could not remain long uncondensed, " surrounded, as it will ever be, by walls always at an even temperature, a short " distance from the ends of the tunnel, saturated with moisture, and the surface " in many parts covered with water.

" The coke, particularly when in a high state of combustion, gives out little " smoke, and, from its having passed through the steam, loses, like the coal, the " greater part, if not all its offensiveness; and mixing with the air that has been " used for combustion, will, from its buoyancy, readily find its way along the " top of the tunnel to the first shaft, and make its escape up it.

" Two great inconveniences in tunnels, are noise and want of light; the former " it will be difficult to remedy, the latter may be easily so, by carrying oil or " portable gas lamps with the carriages. Oil lamps are used with the evening " trains, during the winter months, on the Leeds and Selby Railway, and give " sufficient light in their passage through the tunnel. Some experiments were " made with tin reflectors at the bottom of the shafts, and although the light " reflected was sufficient to read the larger print in a newspaper advertisement " at all parts of the tunnel, (there being three shafts,) it is very doubtful whether " lighting tunnels by reflection will be of use for passengers. The rays of " light are thrown on the walls so very obliquely, that, from the rough and " dirty state of their surface, few are again reflected from them, and these " are too feeble for the eye to accommodate itself to so great a transition " during the time a train would be passing through a tunnel of moderate length. " A passenger sitting in a close carriage, having only the walls to look at, would, " under such circumstances, fancy himself in total darkness, although the tunnel " generally might be moderately light. The difficulty of keeping reflectors clean " from the effects of damp, steam, &c., would be a considerable expense in a long " tunnel; and it must also be borne in mind, that the moment an engine has " passed a reflector, it becomes of no use to the train attached to that engine, as " it is immediately surrounded with steam, &c., forcing its way up the shaft, and " the next reflector, in a long tunnel, would probably be a quarter of a mile from " the one thus thrown into darkness."

VIII. *Particulars of the Construction of the Lary Bridge, near Plymouth. By Mr. J. M. Rendel, Corr.M.Inst.C.E.*

As this bridge is founded on a shifting sand, in a rapid tideway, and presents some novelties in the design, it is hoped that an account of the methods successfully adopted for laying and securing the foundations, and some particulars of the superstructure, will be acceptable to the members of the Institution.

The Lary, over which this bridge is built, and from which it derives its name, is the estuary of the river Plym, and connected with Plymouth Sound by Catwater. The general width of the estuary is half a mile, but at the site of the bridge the shores abruptly approach each other, and form a strait between 500 and 600 feet wide. The tide rushes through this strait with a velocity of 3 feet 6 inches a second, and flows on an average 16 feet perpendicular.—The depth at low water is from 5 to 6 feet.

By borings it appeared that the bed of the river was sand to a depth of 60 feet—the lofty lime rock on each shore dipping abruptly from high water, and forming a substratum nearly horizontal across the strait. The sand in the wide parts of the estuary above and below the bridge is fine; at the site of the bridge the current leaves only the coarser kind; but this is not sufficient to resist the heavy land floods, to which the Plym is liable, and it frequently happens that the bed of the river is scoured away several feet in depth in winter and refilled in the summer.

When called on by the Earl of Morley, who built this bridge at his sole expense, to prepare a design, I furnished one on the principle of suspension, spanning the whole width of the strait, and having the towers on its rocky shores. Our president * was consulted by his lordship, and the plan being approved of by him, an act was obtained in the session of 1823 authorizing its erection; but on the commencement of the works, difficulties arose which led to the abandonment of the suspension bridge and the ultimate adoption of the present one of cast iron.

The drawings (see Plates XIV. and XV.) which accompany this paper, will, I trust, give a general idea of the finished structure. The arrangement of the design

* The late Mr. Telford.

differs materially from other works of a similar nature: first, in the masonry of the piers finishing at the springing course of the arches; secondly, in the curvilinear form of the piers and abutments; and thirdly, in the employment of elliptical arches. The adoption of these forms for the piers and arches in unison with the plan of finishing the piers above the springing course with cast iron instead of masonry, has, as I had hoped, given a degree of uniform lightness, combined with strength, to the general effect, unobtainable by the usual form of straight sided piers carried to the height of the roadway, with flat segments of a circle for the arches.

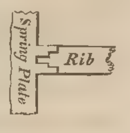
Having given these particulars of the situation and design of the work, I will now add some information as to the proportions of the several parts of the structure.

The centre arch is 100 feet span, and rises 14 feet 6 inches; the thickness of the piers, where smallest, being 10 feet. The arches adjoining the centre are 95 feet span each, with a rise of 13 feet 3 inches. The piers taken, as before, are each 9 feet 6 inches thick. The extreme arches are each 81 feet span, and rise 10 feet 6 inches. The abutments are in their smallest dimensions 13 feet thick, forming at the back a strong arch abutting against the return walls to resist the horizontal thrust. The northern abutment forms a considerable projection, which was deemed advisable in consequence of the obliquity of the adjoining wharf below the bridge; as well as to afford the noble proprietor an opportunity of building a toll-house on extra-parochial ground. The ends of the piers are semi-circular, having a curvilinear batter on the sides and ends formed with a radius of 35 feet, and extending upwards from the level of high water to the springing course, and downwards to the level of the water at the lowest ebb. The front of the abutments have a corresponding batter.

The parts of the piers and abutments which lie under water at the lowest ebbs, are composed of 2 feet courses of masonry with offsets, as will be better understood by reference to the drawing. (See plates.)

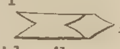
The roadway between the abutments is 24 feet wide, supported by 5 cast iron equidistant ribs. Each rib is 2 feet 6 inches in depth at the springing, and 2 feet at the apex by 2 inches thick, with a top and bottom flange of 6 inches wide by 2 inches thick, and is cast in 5 pieces; their joints, (which are flanged for the purpose,) are connected by screw pins with tie plates equal in length to the width of the roadway, and in depth and thickness to the ribs; between these meeting plates the ribs are connected by strong feathered

crosses, or diagonal braces with screw pins passing through their flanges and the main ribs. The springing plates are 3 inches thick, with raised grooves to receive the ends of the ribs, which have double shoulders, thus:



These plates are sunk flush into the springing course of the piers and abutments, which, with the cordon and springing course, are of granite. The pier standards and spandril fillings are feathered castings, connected transversely by diagonal braces and wrought iron bars passing through cast iron pipes, with bearing shoulders for the several parts to abut against. The roadway bearers are 7 inches in depth by $1\frac{1}{2}$ thick, with a proportional top and bottom flange; they are fastened to the pier standards by screw pins through sliding mortices, whereby a due provision is made for either expansion or contraction of the metal—the roadway plates are $\frac{7}{8}$ of an inch thick by 3 feet wide, connected by flanges and screw pins, and project 1 foot over the outer roadway bearers, thus forming a cornice the whole length of the bridge.

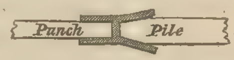
After what has been stated of the character of the river and nature of its bed, it is unnecessary to remark that extreme caution was indispensable in preparing and securing the foundations.

We commenced by driving sheeting piles to a depth of 15 feet around the whole area of the base of the piers and abutments. These piles are of beech plank, 4 inches thick, having their edge grooved to fit thus, , and were driven in double leading frames fixed to temporary guide piles:—great attention was paid to have them perfectly close. When pitched they were from 16 to 18 feet long, properly hooped and shod with plate iron shoes, weighing on an average 2 lbs. each. These piles were driven with a cast iron weight of 450 lbs. worked by seven or eight men in what is termed a ringing engine. They were driven several feet below low water by means of punches.

As these pilings were carried on, the sand was excavated from the space they enclosed to a depth of 5 or 6 feet below the general level of the river, and from 9 to 10 feet below the level of low water of ordinary tides. These excavations were effected by means of sand spoons of the following construction. Strong canvas bags, capable of containing about 2 cubic feet of sand, were firmly secured to elliptical rings of wrought iron, each ring having a socket to receive a long wooden handle in the direction of its transverse axis, and a swivel handle through its conjugate axis. Stages were fixed on the leading frames in which the sheeting piles were driven, at about 3

feet above low water, and each spoon was worked by three men in the following manner:—a rope was fastened to the loop in the swivel handle of the spoon frame, one end of which was passed over a single block fixed a few feet above the level of the stage, and the other end was held by one of the workmen, whose business it was to pull the spoon when at the bottom towards him, while a second pressed it downwards and guided it, by means of the long wooden handle, till it was thought to be filled; the third man, who was stationed at the rope which worked through the single block, then hoisted the spoon to the stage and discharged its contents into a shoot, which drained into the river. After the labourers had become used to the work, these operations were carried on with considerable despatch, favourable tides generally affording from 3 to 4 hours' work per day.

As these excavations proceeded, the ground was piled with whole timbers of large Norway and small sized Memel, and as many of beech as could be procured of the desired length; these piles, being properly shod and hooped, were driven from temporary stages, fixed above high-water level, by weights varying, according to the size of the pile, from 10 to 15 hundred weight; they were disposed in five rows, in the width of the foundations, from 4 feet to 4 feet 6 inches from centre to centre, and were driven till they did not sink more than one inch with eight blows of the 15 hundred weight driver falling from a height of 25 feet, and then received twenty additional strokes with the same weight and fall.

These piles, none of which were less than 35 feet long, were driven to the level of the stage, and then punched to their proper depth. The punches used for this purpose were made of sound and well seasoned elm, hooped throughout their length, and having at their lower ends a strong cast iron ring, about 18 inches wide; this ring had a thick partition plate, cast in the middle of its width, which separated the head of the pile from the end of the punch; the lower end of the ring was cast a little conical, and the pile heads were made to fit it accurately thus 

. By this means the pile heads were but little injured, and the loss of momentum occasioned by the intervention of a punch was reduced to a mere trifle.

The next operation was to cut off the bearing piles to their proper depth, and to pave and grout the spaces between them. The usual mode of coffer-dams was manifestly inapplicable to such a bed of sand; I therefore, in an early stage of the works, proposed to the contractors that the pile heads should

be levelled, and the spaces between them paved by means of a diving bell. To save expense, this bell was made of wood, and with the necessary machinery was finished and put to work within six weeks from the time it was determined on. With its assistance the works were carried on with expedition and success. When in operation it contained two men, who, being provided with the necessary instruments for cutting off the piles, paving the spaces between them, &c., continued at work for four hours, when they were relieved by two others.

As much depended on the regularity with which the pile heads were levelled, great care was bestowed on this part of the work. It was accomplished in the following manner:—the four angular piles of each foundation being cut as low as the water would permit, were accurately levelled from a plug on the shore, to ascertain how much each had to be reduced to bring it to its proper level; on each of these piles was marked the portion remaining to be cut by the bell men, which being done, all the remaining piles were levelled from them, by means of a spirit-level, accurately adjusted in a piece of wood, sufficiently long to be applied to three piles at a time. The paving between the pile heads was performed in an equally simple and satisfactory manner.

As this economical bell answered every required purpose, a general description of the whole apparatus may prove acceptable.

The internal dimensions of the bell were 5 feet 6 inches in length, 4 feet 6 inches in width, and 5 feet in height; the sides, ends, and top were made of two thicknesses of $1\frac{1}{2}$ inch well seasoned elm board; the inner case was constructed with its joints parallel to the top and bottom or mouth of the bell, whilst those of the outer one were vertical, or at right angles to the inner joints; the top joints were crossed in the same manner as the sides; all the joints had a slip of flannel, saturated in a composition of bees' wax, laid between them, and were dowelled together and set as close as possible by means of screw clamps, &c., the sides were rabbeted to the end, and the internal angles were strengthened with brackets. The whole surface between the inner and outer case was covered with double flannel, saturated as just described, and was then connected together by a number of wooden pins, dipped in tar and tightly driven; the top was perforated with six holes of 6 inches diameter each, in which was firmly fixed a corresponding number of

strong lenses set in white lead; a hole of 3 inches diameter was made in the centre, in which was fixed a brass pipe with a screw to attach the air tube; four hoops of wrought iron, two internal and two external, were screw-bolted together through the sides and ends of the bell: internal and external cross-lacings were also screw-bolted to those hoops, and to the sides and top of the bell. In these lacings, the chains by which the bell was suspended, were fixed in strong iron eyes, which passed through the top of the bell, and were riveted to the inner lacings. All the screw-bolts were driven with tarred oakum, and every precaution was taken to render the whole air-tight. The bell thus finished weighed about 1 ton 10 hundred weight, but it required from 5 to $6\frac{1}{2}$ tons to sink it, and overhaul the ropes by which it was suspended; cast iron plates, from $1\frac{3}{4}$ to 2 inches in the thickness, were therefore hung externally round its sides and ends, till it was sufficiently loaded to sink with steadiness in about 25 feet of water.

The bell was provided with two movable seats and a foot-board for the divers, and at top long boxes were fixed, in which their tools were kept; it was supplied with air by a double acting force-pump, the cylinders of which were 7 inches diameter in the clear, the pistons making a 14 inch stroke. This pump was generally worked by four men, and made, on an average, according to the depth of water and run of the tide, about eight double strokes per minute.

Around the foundations on which the bell was to be employed, temporary piles were driven, and cut off level about 15 feet above high water, and cross braced; on the top of these piles whole Memel timbers were firmly fixed, care being taken to have the side beams parallel to each other. A strong frame, equal in length to the distance between the parallel beams of the above stage, and about 4 feet wide, mounted on four small cast iron flanged wheels, traversed on an iron railway laid on the beams; this frame was moved on the railway by means of a rope connected to the sides, and worked by two common winches, one fixed at each end of the stage; on the beams of this traverse frame a railway was also laid, on which worked a carriage, mounted in a similar manner, and sufficiently large and strong to carry a purchase machine capable of raising the bell by the labour of four men; the bell was suspended to this carriage by two treble blocks, the upper block being lashed to one of the cross beams of the frame, and the lower connected to the sling chains of

the bell by a strong shackle. This traverse frame was easily moved by winches affixed to the ends of the long frame, over which ropes worked, having their ends made fast to the purchase machine frame.

By these traverse frames the bell was moved with great celerity to any part of the foundations. The machinery required the attendance of six active men, viz. one to each of the four winches, and two to the purchase machine. It was the sole business of a careful man to attend to the signals of the divers, and to direct the men at the machinery and air-pumps accordingly. The signals were communicated by a line, one end of which was fixed in the bell, and the other held by the signal-man, whose place was on the stage. To avoid confusion in the signals, any thing requiring great precision was communicated to either the divers or signal-man by means of a board attached to the line on which either party wrote with chalk, and by these means a regular correspondence could be carried on.

By means of the bell and apparatus, the works proceeded with safety and expedition, and I feel confident that diving-bells may be employed by the bridge builder in a variety of cases with much greater advantage and economy than coffer-dams.

The foundations being prepared, and guides fixed to the plank piles, caissons were floated off from the shore with one, and in some instances two courses of masonry, and sunk. The greatest success attended these operations from the care that was taken to get the foundations perfectly level: of course, the heads of the plank piles were not cut off until the caissons were sunk.

The bottoms of the caissons were made of beech plank and beams; the bottom plank was 4 inches thick and laid in the transverse direction of the pier, across which the beams 12 inches by 8 inches were placed so as to correspond with the rows of piles in the foundation. The spaces between the beams were filled with masonry set in Pozzuolana mortar, and grouted; and a flooring of 3 inch plank, closely jointed and well caulked, so as to be perfectly water-tight, covered the masonry and beams. The top and bottom planks were trenailed to the beams, and the whole strengthened by a strong frame of beech, a foot square, surrounding the bottom and fastened to it by strong screw bolts and trenails.

The upper surfaces of the beams of this frame were grooved to receive a strong tongue, fitting a corresponding groove in the bottom beams of the sides and ends of the caissons, which were made in the usual way, and connected

to the bottom by strong lewes irons fitted to cast iron boxes, firmly fixed in the bottom planking. The lewes irons were fixed about 8 feet apart, and were easily removed when the masonry was brought up to the height of the caisson. The introduction of the tongue in the bottom beams of the caisson proved of the greatest utility, as it prevented leaks from the slight sinkage of the bottom between the lewes irons, which it is impossible to prevent when the caisson grounds.

The caissons were furnished with sluices, and made 15 feet high, which gave the masons an opportunity of working about five hours each tide on an average of neaps and springs.

The masonry of the piers and abutments is composed of solid compact limestone, raised in the quarries of the noble proprietor of the bridge* in the adjoining cliffs, and Dartmoor granite, the latter used only, however, in the springing courses and cornices. The limestone is quarried in masses, varying from two to six tons weight, and these were taken to the work on a railroad, continued from the quarries across the river on a stage or temporary bridge, passing close to the piers and abutments, and under the stages on which the diving bell was worked as before described, and the machinery used in working the bell was applied to taking the stone from the waggons, and in setting it. This machinery was found of incalculable advantage in building with such heavy blocks of stone, moving them with ease and the minutest accuracy from over head, and, consequently, without obstructing or incommoding the builders in the caissons.

Experience having taught me that the mortar used in the construction of these works is of an excellent quality, I shall, I hope, be excused if I add to this already long paper a few words on this subject.

The blue lyas stone got from the coast of Dorsetshire was burnt at the bridge as the works proceeded, and, whilst hot from the kiln, was ground in a mill to a fine powder. It was then taken to another mill, and in its powdered state mixed with prepared Pozzuolana and sand, and ground until it formed a tough paste, no more water being used than was absolutely necessary. The best mortar, or that used in the bottom courses of the piers and abutments, and for the front work, was composed of one measure of powdered lime, one measure of Pozzuolana, and two measures of sand. The backing mortar was prepared with one measure of lime, half a measure of Pozzuolana, and two measures and

* From these quarries the large blocks of stone used in paving the breakwater are taken.

a half of sand: the sand was of an excellent quality, got from the site of the bridge.

The following circumstance will sufficiently prove the goodness of this mortar. Some masonry, which had been done in one of the foundations about twelve months, had to be removed, when the stones were found so firmly united, that gunpowder was necessary to separate them.

I have before described the bed of the river to be a loose sand moved by the slightest increase of current, and that this circumstance, together with the difficulty of founding piers and abutments, induced me to propose a suspension bridge spanning the whole width of the river. It was however hoped, when a change of plan became necessary, that the plank piles, with the aid of some stone thrown round them, would be sufficient to meet the increased current occasioned by the bridge; but as the erection of the piers and abutments proceeded, the necessity of a more extended security for the foundations became manifest, as the bed of the river, for its whole width, and to an extent of from 50 to 60 feet above and below the bridge, was gradually scouring away. I therefore proposed to form an artificial bed, to the full extent to which the natural one was removed, with clay from 18 inches to 2 feet thick, and to cover the clay with rubble stone of all sizes from 200 lbs. each downwards. This plan of operation was suggested by observing these materials in vast abundance in the adjoining limestone quarry spoil hills, and after I had submitted the clay to experiment, and found it capable of resisting a current acting immediately upon it at a velocity of 7 feet per second. The clay and stone were deposited with great regularity, giving to the channels under each arch a slight concavity in the middle: the combined thickness of the clay and stone is from 2 feet to 2 feet 6 inches, and just replaces the loss of the natural bed.

By this union of materials an indestructible bed has been produced. The clay shields the natural bed from the current, whilst at the same time it forms a tenacious cement in which the stone buries itself, and which is hardened by the volume of water constantly pressing on it. In six months after this work was finished, I ascertained that sea weeds were growing over its surface, and that it was sufficiently firm to resist an oyster dredge*.

* At the present time (1836) the surface is so hard, that heavily laden waggons would not sink in it.

Messrs. Johnson of Grosvenor Wharf, London, were contractors for the masonry, &c., and Mr. William Hazledine, of Shrewsbury, for the iron work.

The contract amount for the masonry, &c., was . .	£13,365	0
Ditto ditto for the iron	13,761	0
Making the total cost	£27,126	0

The work commenced in August 1824, and the Bridge was opened in July 1827.

IX. *An Abstract Account of Coals used in Coke Ovens and Retorts, and Coke produced from One Year's Work at the Ipswich Gas Works. Communicated by* WM. CUBITT, *Esq., F.R.S., &c., V.P.Inst.C.E.*

1825.	Coals used in Ovens.		Coke produced.		Coals used in Retorts.		Coke produced.	
	Ch.	Bu.	Ch.	Bu.	Ch.	Bu.	Ch.	Bu.
January	31	32	36	9	37	18	55	16
February	28	20	29	27	27	18	40	34
March	27	10	31	15	25	0	37	4
April	16	24	19	7	16	18	24	15
May	15	15	17	35	7	24	11	16½
June	15	6	17	24	6	0	5	32½
July	15	18	18	1	7	6	10	27
August	24	4	28	0	8	17	12	22
September	30	0	34	29	27	0	39	16
October	33	4	38	22	30	20	45	25
November	34	18	40	18	35	2	51	32
December	41	4	46	6	45	20	70	0
	313	11	358	13	273	35	405	24

Experiments to shew the Weight of Coke produced from both Coke Ovens and Retorts with a given Weight of Coals.

COKE OVEN EXPERIMENTS.	Measure of Coals.		Weight of Coals.			Weight of Cinders.			Measure of Cinders.	
	Ch.	Bu.	Cwt.	qrs.	lbs.	Cwt.	qrs.	lbs.	Ch.	Bu.
1st Experiment in Ovens with TM coals	0	20	13	3	11½	8	0	22	0	22½
2d ditto ditto with same coals	0	20	13	2	18	8	0	20	0	22½
RETORT EXPERIMENTS.										
1st Experiment in 6 Retorts with small coals	0	10	6	0	0	4	3	5	0	12
2d ditto in 6 Retorts with TM coals	0	10	6	2	15	4	3	20	0	14

The coke ovens from which the above statement is made are worked with a daily charge of 20 bushels of coals, which are burned off in 24 hours.

Each oven, by means of its spare heat, keeps at a constant working state 6 retorts for making coal gas, which retorts are charged with 10 bushels of coals three times per day in a general way.

The coke produced from the ovens is the best possible quality for iron-founders and maltsters, and is sold at 28*s.* per chaldron of 36 bushels.

The coke produced from the retorts is used by some persons for drying malt, but principally for common fires, and is sold at 21*s.* per chaldron.

The coals which are found to yield the greatest heat in converting into coke in the ovens, and at the same time leaving the best coke, are *Pitt's Tanfield Moor*, fitted only by H. Clayton, of Newcastle.

The waste heat from these coke ovens keeps the retorts at a constant red heat through an entire coating of fire-bricks, varying from 8 to 3 inches in thickness, according to the distance from the end of the coke oven.

X. *An Approximative Rule for calculating the Velocity with which a Steam Vessel will be impelled through still Water, by the Exertion of a given Amount of Mechanical Power, or forcible Motion, by Marine Steam Engines. Communicated by Mr.* Farey, *M.Inst.C.E.*

Notwithstanding the great experience which has been acquired in constructing steam vessels, few engineers possess any rule for determining *à priori*, what will be the speed of a new vessel, which is designed.

The usual course is, to institute to a comparison with some former steam vessel, whereof the dimensions and performance is known, and by estimating all the differences of dimensions between that former vessel, and the new-intended one, the difference of its expected performance from the known performance, is inferred. When the new intended vessel is not materially different from some previously known case, this method of comparison answers the purpose; but so many cases arise in practice, which are not comparable with any known case, that a general rule is greatly wanted, and the writer of this communication has kept the subject in view, from the first establishment of steam vessels till the present time, omitting no opportunity of ascertaining and recording the performance of every steam vessel whereof the form and dimensions could be ascertained, and at intervals arranging the observations in classes, and deducing rules from them, which have been amended and improved from time to time, as more complete information was attained.

Almost all experiments which have been made, on the resistance of drawing floating bodies, along the surface of unconfined, but tranquil water shew, that the resistance increases as the square of the velocity; and hence it may be inferred, that if the draft, or direct pull, (such as horses exert on the towing line of a canal boat,) which is requisite to draw a vessel along the water at a rate of five miles per hour, is one ton, then to draw it at the rate of ten miles per hour, will require a pull of four tons.

It follows as a consequence, that the exertion of mechanical power, or forcible motion, must progress according to the cubes of the velocities, because an increased force is to be exerted with an equally increased velocity; for instance, if an exertion of 25 horse power will impel a given vessel at the rate

of five miles per hour, it would require an exertion of 200 horse power, to impel the same vessel at the rate of ten miles per hour.

These two propositions are to be considered as assumptions, when applied to steam vessels, because the experiments on which the first is founded, viz., the rate of resistance being as the square of the velocity, have been all made on very small vessels, nevertheless they all concur in very nearly the same result*; and again, in steam boats, the water yields very considerably to the paddles, and a loss of power is thereby occasioned†, which is not contemplated in framing the second proposition, (viz. that the power exerted must be as the cube of the velocity, because the resistance of draft is as the square of the velocity.)

* A fund of valuable information on this subject is contained in the papers of the late Colonel Beaufoy. Since the above was written, those papers have been published by his son in a quarto volume, which has been distributed in the scientific world; a copy is preserved in the library of the Institution.

† This loss had formerly a much greater influence than at present; because the improvements which have been made in proportioning the paddles of modern steam boats, has rendered the loss less considerable. I was formerly induced to suppose that the exertion of power increased by a higher ratio than the cubes of the velocities attained by the exertion. This notion arose in the course of some of my earliest deductions, from observations on the steam boats first used in Scotland; comparing their increase of speed with the power exerted by successive engines, of greater and greater magnitude, which were substituted one after another on board the same boats, it appeared that the exertion of power required to produce different velocities, corresponded to some intermediate stage between the cubes and the biquadrates of those velocities; an arithmetical mean between the cube and the biquadrate seemed nearly to correspond to those observations, but subsequently it was found out, that the loss occasioned by the yielding of the water to the paddles, had been very greatly increased when larger engines had been first substituted for smaller engines, but when larger paddle wheels, and paddles, were given to the larger engines, the speed was improved, and when so improved the power exerted came out nearly as the cubes of the velocities.

This notion would be no more worthy of being recorded than a multitude of other attempts to deduce rules from uncomparable observations, if a rumour of it had not, unknown to me, found its way into a memoire upon navigation by steam, read before the institution at Paris in 1826, by M. Seguin, who relates that he consulted me, when I resided at Leeds, and that I considered the resistance of vessels to be proportional to the fifth powers, divided by the cubes of the velocities, which Mr. Seguin says confirmed some opinions of his own.

Now the fifth power of any number being divided by the cube thereof, is only the same as the square of the number, and that is the proportion of force of draft, which I have always assumed to be requisite for overcoming the resistance of pulling a vessel through the water, with different velocities; but the mechanical power, or forcible motion, which must be exerted by a steam

Notwithstanding any doubts which may be entertained of the exactitude of the last proposition, the following rule (which proceeds on the assumption, that the impelling power which must be exerted, is as the cube of the velocity) will be found to give results which approximate to the actual performance of steam vessels in common use.

The rule contemplates the extent of surface which the bottom of the vessel exposes to contact with the water, and also the sectional area of the water which must be divided by the vessel, in advancing forwards; and numbers representing those two quantities, are combined into one sum, which is taken to represent the resistance of the vessel, compared with any other vessel of a different magnitude, but similar in form, the speed in both cases being equal.

In estimating the power exerted by the engines, the rule supposes the actual power, as shewn by the indicator, with due allowance for friction, not the nominal power by which the engines are rated, which in modern engines is always very much less than the power actually exerted. For instance, Messrs. Boulton, Watt, and Co.'s marine engines, are calculated to exert about $7\frac{3}{10}$lbs. effective force, for each square inch of their pistons, and the motion of the pistons in their cylinders causes an expenditure of $31\frac{4}{10}$ cubic feet of steam per minute, for every nominal horse power*, being a little different from their scale for land engines.

Messrs. Boulton, Watt, and Co.'s 50 horse marine engines, have cylinders $39\frac{1}{2}$ inches diameter, their pistons moving $3\frac{1}{2}$ feet stroke, and are calculated to make $26\frac{1}{2}$ strokes per minute. Their 80 horse marine engines, have cylinders $47\frac{1}{2}$ inches diameter, pistons $4\frac{1}{2}$ feet stroke, and calculated at $22\frac{1}{2}$ strokes per minute.

When a trial of any modern marine engine is made by an indicator, the effective or unbalanced pressure of steam, by which the piston is impelled, will be found much more than the assumed $7\frac{3}{10}$lbs. per square inch, after allowing

engine, in order to overcome that resistance, I assume to be as the cubes of those velocities; I explained to Mr. Seguin, that formerly I had supposed it to be a more rapid rate of increase than the cubes, something like an arithmetical mean between the cube and the biquadrate as above stated. The fifth power divided by the cube, was a statement made to me, and to which I assented, as giving correct results for the resistance of draft; but it is a needlessly complicated mode of expressing the square of a number. J. F.

* That horse power being in all cases, according to Mr. Watt's standard, a force of 33,000lbs. acting through a space of one foot per minute.

amply for friction; $11\frac{1}{2}$ lbs. per square inch is probably nearer to an average of good engines; but the very best are considerably more, even as much as $12\frac{1}{2}$ lbs. per square inch. The actual power exerted, will be greater than the nominal horse power, in proportion as the actual force exerted by the piston is greater than the assumed standard of $7\frac{3}{10}$ lbs. per square inch.

The approximate rule is as follows:—

I. Find the area of the transverse section of the vessel, under water, in square feet; extract the square root of that number of square feet; multiply the root by the length of the vessel at the water's surface, and divide the product by the greatest breadth of the vessel at the water's surface; then add the quotient to the above number of square feet; the sum is to be taken for a representation of the resistance of the vessel, compared with others of different sizes, but similar in form, the comparison being made, by the above mode of computation, when they are proceeding with the same velocity.

II. Find the number of horse powers actually exerted by the engines, according to observations made by the indicator, and multiply that number by 1000, in case of vessels of an ordinary form, such as were usually built for sea-going vessels seven years ago*; divide the product by the number previously found as above; then extract the cube root of the quotient; and that root will be near to the velocity of the vessel, in miles per hour, through still water.

Example, of a large vessel, 150 feet long, 27 feet broad, drawing $9\frac{1}{2}$ feet water, impelled by two engines rated at 80 horse power each; she went $9\frac{7}{10}$ miles per hour (in 1826).

The sectional area of the part under water, was 207.6 square feet; the square root of that is 14.4, which multiplied by 150 feet long, and the product divided by 27 feet broad, gives 80 for a representation of the surface of the bottom in contact with the water, and that added to 207.6 square feet, gives 287.6 to represent resistance. The engines were found by the indicator, to exert an effective force of $11\frac{1}{2}$ lbs. per square inch of their pistons, (friction being allowed for,) when they made 23 strokes per minute, of $4\frac{1}{2}$ feet; the pistons being $47\frac{1}{2}$ inches diameter; that is, 128 horse power, actually exerted by each engine, or 256 horse power by both, this being multiplied by 1000, gives

* For the very full built forms, such as were used for the early steam boats, built more than 14 years ago, the multipliers should be only 900; or for the very sharp improved forms built in the last two or three years, 1100.

256,000, which product divided by 287.6 gives 890; and the cube root thereof is 9.62 miles per hour, instead of 9.7 miles, as observed.

Another example, of a small vessel, 105 feet long, $17\frac{1}{2}$ feet broad, drawing $5\frac{1}{4}$ feet of water, impelled by one engine, rated at 50 horse power; she went $9\frac{2}{3}$ miles per hour (in 1829).

The sectional area was 62 square feet; square root thereof 7.87×105 feet long $\div 17\frac{1}{2}$ feet broad $= 47.25$, to be added to 62, making 109.25 to represent resistance. The piston, according to the indicator exerted $12\frac{1}{2}$lbs. per square inch effective force, (after allowing for friction,) and made 30 strokes per minute of $3\frac{1}{2}$ feet, piston $39\frac{1}{2}$ inches diameter, that is, an exertion of $97\frac{1}{2}$ horse power; multiply that by 1000, and divide by 109.25, gives 892, the cube root of which is 9.626 miles per hour.

The above two vessels being the same in speed, but very different in magnitude, the accordance of the results given by the rule with the facts, shews that the rule makes a proper allowance for difference of magnitude.

Another example, of a small boat, 72 feet long, 15 feet broad, a very full built form, impelled slowly, by one engine of the oldest construction, called 10 horse power, made in Scotland, 1814.

Sectional area 42 square feet; square root thereof 6.48×72 feet long $\div 15$ feet broad $= 31.1$, to be added to 42, making 73.1 to represent resistance. The engine was very inferior to the modern ones*, and probably did not exert above $7\frac{1}{2}$lbs. per square inch of the piston, which was 22 inches diameter, 2 feet stroke, and made 32 strokes per minute, that would be 11.1 horse power. The form of this old boat being very round at the bows, and more resisting than the modern vessels, should have a lower multiplier, viz. 900 instead of 1000; therefore 11.1 horse power $\times 900 \div 73.1$ resistance, gives 136.7; the cube root of which is 5.15 miles per hour, which was very near the real speed of this boat.

Another example, of an old boat, 156 feet long, 33 feet broad, in America, 1816, impelled by one engine, piston 40 inches diameter, 5 feet stroke, 17 strokes per minute, she went $6\frac{1}{2}$ miles per hour. Sectional area 150 square

* In those older examples previous to 1819, wherein no indicator observations were made upon the engines, the probable force exerted by the pistons, has been inferred from indicator observations, made since, upon other engines of similar structure and proportions of their parts.

feet; square root $12.25 \times 156 \div 33 = 57.9$ to be added to $150 = 207.9$ for resistance; the piston probably exerted about $9\frac{1}{2}$lbs. per square inch, which would be 61.5 horse power*. The form of this boat being very full, multiply by 900 and divide by $207.9 = 266.5$, the cube root of which gives 6.43 miles per hour.

Another example, of a small boat, 85 feet length, $18\frac{1}{2}$ feet wide, $3\frac{3}{4}$ feet draft of water, impelled by two engines, pistons 22 inches diameter, $2\frac{1}{2}$ feet stroke, 34 strokes per minute (in 1818). Sectional area 62 square feet; square root thereof 7.87×85 feet length $\div 18\frac{1}{2}$ feet wide $= 36$, which, added to 62, gives 98 to represent resistance. The engines were the earliest construction of combined engines, and probably their pistons did not exert above $7\frac{3}{4}$lbs. per square inch*; which would be 30.3 horse power. The boat was sharper than those of the older construction, being very similar in form to those before calculated with 1000 for a multiplier, which being used and $\div$ 98 resistance, gives 309, the cube root of which is 6.76 miles per hour. The boat actually went $6\frac{2}{3}$ miles per hour.

Another example, of a large vessel, 136 feet long, 26 feet wide, $12\frac{1}{2}$ feet draft of water. Impelled by two engines rated at 60 horse power each, she went $8\frac{1}{2}$ miles per hour, 1825. Sectional area 227 square feet; square root $15.07 \times 136 \div 26 = 78.8$ to be added to 227, making 305.8 to represent resistance. The pistons 43 inches diameter, 4 feet stroke, 26 strokes per minute, exerting $11\frac{3}{4}$lbs. per square inch, which is $107\frac{1}{2}$ horse power by each, or 215 horse power exerted by both engines. The form of the vessel was full, such as requires 900 for a multiplier; and 215 horse power $\times 900 \div 305.8$ gives 633; the cube root of which is 8.59 miles per hour.

The above examples shew that the rule applies to cases where the difference of speed is very considerable, as well as the difference of magnitude.

25th April, 1833.

* Vide note, p. 115.

XI. *On the Effective Power of the High-Pressure Expansive Condensing Steam Engines commonly in use in Cornish Mines. By Mr. T. Wicksteed, Civil Engineer. Communicated in a Letter to the President.*

At your request I beg leave to forward you some observations upon Cornish engines, which, although not entering into the detail you seem desirous of obtaining, will not, I trust, be quite devoid of interest.

Having received instructions from the Court of Directors of the East London Water Works to visit the mines in Cornwall, for the purpose of making inquiries about the Cornish engines, I left London upon the 1st of August last, and returned upon the 20th of the same month.

My friends, Mr. John Taylor and Mr. Grout, kindly gave me letters of introduction, which enabled me to see any engine I was desirous of viewing.

The first mines I visited were the Wheel Friendship copper mines, near Tavistock, Devonshire, and the Redmoor and Holmbush copper, and the Wheel Brothers silver, mines, near Callington, Cornwall. At the Redmoor mine I saw an engine with a 50 inch cylinder, erected by Messrs. Petherick and West. The mine had not been long at work; the shaft was not more than 156 feet deep; there were two shafts with pumps in, and one was about 560 yards distant from the engine; the motion was communicated by means of horizontal bars, suspended by pendulum rods. The engine was working about two strokes per minute throughout the 24 hours; the work done was light, probably not equal to more than five horses' power; it consumed only three and one-third imperial bushels of coals per 24 hours. The engine had been worked the previous fortnight with turf cut off the neighbouring moor, at a cost of eight-pence halfpenny per 24 hours; it required 18 feet square of turf, about 2 inches thick, to keep the steam up for that time. I mention this to shew that when a large engine is erected to clear a mine, although in the first instance the work it has to do is not proportioned to its size, nevertheless, the consumption of fuel is nearly in proportion to the work done.

As regards the use of turf, it is evident, as these boilers were constructed with the intention of using coal as fuel, when the depth of the mine and the quantity of water increased, that turf could not be used without an alteration

in the fire-places, the bulk of turf required being much greater than that of coal. Mr. Grout has since informed me, that he has ordered an engine and boilers for one of his mines, and that the boilers are to be constructed with a view to the use of turf only.

The next engine that I saw was one at the Fowey Consolidated mines, near St. Blazey. The cylinder was 80 inches, the pump stroke $9\frac{1}{4}$ feet, the duty was, in August, equal to 83,296,000 lbs., raised 1 foot high, with an imperial bushel, or 84 pounds of coals; it consumed about a bushel or 84 pounds of coals per hour. This is a most splendid engine, and does greater "duty" than any other engine in Cornwall; the construction of the valves and other parts of the engine is so perfect, that although its load was equal to about 51,000 lbs., the hand-gear might be worked by a boy of ten years of age, as far as strength was required; I worked it myself with perfect ease; whereas, although the load upon one of our engines of 36 inches cylinder is only about 12,000 lbs., it requires not only a strong, but also a weighty man to work it.

The hand-gear is all bright work, and finished in first rate style. The quantity of bright work in an engine of course depends upon the taste of the person ordering it, and I certainly saw many Cornish engines of longer standing than the one in question, that displayed very little bright work; but that it can be executed as well in Cornwall as in any other county in England must appear evident to those who have seen this engine, and the founderies or engine manufactories at Hayle. At the latter place I saw an 80 inch cylinder, 12 feet long, in the boring machine, and could not perceive a flaw in it.

I was very much struck with the ease with which the engine in question appeared to work; there was scarcely any noise, the greatest was that of the steam in its passage through the expansion valve. To one who had been used to the noise of the pumping engines in London, it appeared remarkable.

The reason that this engine does more work than any other in Cornwall is, in my opinion, owing chiefly to the construction of the boilers, which are different to the generality, inasmuch as they have an internal tube, of about 21 inches diameter, passing through the main flue of the boiler, extending from the back part of the boiler as far as the bridge of the fire-place, dividing the flame as it passes from the fire-place, and thus where the heat is most intense the surface exposed to its action is greatest; there is also a tube of about the same diameter, and 36 feet long, around which the flue from the boilers passes before entering the chimney; into this tube the feed is sent before it passes

into the boilers, and is previously heated to a temperature of 180° by means of the heat that might otherwise pass into the chimney unused.

The engines that I next viewed were the following; viz.

50	inch cylinder	at Charleston,	Near St. Austel.
76	Ditto	at East Crennis,	Near St. Austel.
66	Ditto	at Polgooth,	Near St. Austel.
85	Ditto	at the Consolidated Mines,	Near St. Day.
80	Ditto	at Ditto,	Near St. Day.
30	Ditto	at United Mines,	Near St. Day.

Although all of these engines were good ones, they were not equal to the Fowey Consols; as regards the last, viz. the 30 inch cylinder, the water that is raised out of the mine by this engine is conveyed by a pipe above ground to supply a water-wheel; and, although it is small and not of modern construction, it is doing nearly twice the "*duty*" of the London pumping engines of 4 times greater area in the cylinder. I mention this engine particularly, because it is doing precisely the same work that a water-works engine has to do in lifting water into a reservoir.

I afterwards viewed the following engines; viz.

Two 80	inch cylinders	at Wheel Vor, near Helston.
One 70	Ditto	at North Roskear, near Redruth.
60	Ditto	at South Roskear, near Ditto.
80	Ditto	at Wheel Darlington, near Marazion.
30	Ditto	at Wheel Providence, near St. Ive's.

The 30 inch cylinder at the United Mines, the 80 inch cylinder at Wheel Darlington, and the 30 inch cylinder at Wheel Providence, were raising the water out of the shafts to the *surface*, and I had therefore an opportunity of seeing it as it was thrown up, and I observed that in every case there were no bubbles of air mixed with the water, proving that the pumps were lifting "solid" water, (as it is termed in Cornwall,) and not partly water, and partly air, as has been suggested by those who have no faith in the reports of the work done by the Cornish engines.

The foregoing, with the exception of the engine at Wheel Jewel Mines, near St. Day, which was not at work while I was there, were all the engines that I saw. And before I proceed to make any further remarks upon them, I beg to call your attention to the Table* that accompanies this Report, which gives further particulars of them, extracted from the "Monthly Reports."

* This "Table of work performed, &c., in January, 1835," is omitted.

As the accuracy of these Reports has been questioned, or to use plainer language, as it has been asserted that they are false, and that the Cornish engines do not perform the work stated, it may be as well to explain how these Reports are made.

When the agents of a mine wish the "duty" of their engines to be published, an accurate measurement of the lifts is made and the diameter of the pumps, and other particulars, are recorded; a counter is fixed upon the engines by Captain Thomas Lean, (the gentleman who has been appointed by the proprietors of the mines to take an account of the work of their engines,) and this counter has a Bramah's lock attached to it, the key of which he keeps. He visits each of the mines once per month, and takes an account of the strokes made by the engines during the preceding month. In some instances there is another counter attached to the engine, which is open to the inspection of the engineer, agents, and engine-keepers.

The coals are supplied by a distinct party, who has to account to the agent of the mines for the coals consumed per month; the engine-keepers write orders for the coals they require, and at the end of the month the quantity of coals on hand is measured and deducted; the orders are considered as vouchers, which, after having been examined and countersigned by Captain Thomas Lean, are passed. It is obviously the interest of the coal agent not to report a less quantity than actually is consumed, being accountable for the quantity used; he cannot therefore be supposed to combine with the engine-keepers, whose object, if dishonest, would be to report a less quantity.

But supposing, for the sake of argument, that the engineers, and the agents of the mines, were so disposed, and could get these gentlemen to combine with them for the purpose of making a false report, the insanity of such a proceeding will, I think, appear evident upon a perusal of the following statement.

The engines in Cornwall are designed, the drawings made, and the construction and erection of the machinery superintended, by gentlemen who are appointed as engineers to look after the machinery of the mines. The castings are made, and the work designed by the said engineers is executed, at two large "foundries," or engine manufactories, at Hayle.

There are more than twenty engineers employed in the mines in Cornwall, all of whom are anxious to construct the best engine, as the parties producing the engines that do the best duty, obtain, of course, the most employment. It is therefore a matter of jealous attention on the part of these gentlemen to take care that no engine shall have undue credit for doing the most work. It

happens occasionally, where a great improvement has been made, that doubts are expressed as to the accuracy of the reported duty: in such cases the engineers and agents of the other mines call upon the parties whose engine is reported as performing extraordinary duty to allow them to prove it; this call is answered by fixing a time for the trial—the trial lasts for two or three days, during which time the engine is in the hands of the rival parties, who are on the watch to detect unfair play, if any should be attempted. If the result of this trial is favourable, the party in question receives due credit; if otherwise, his character as an honest man is lost. If this is not as severe a test of the accuracy of the reports as can be made, and not sufficient, then indeed prejudice must have its full swing, and no farther *proof* can be given, as gentlemen going into Cornwall from London and elsewhere, for the purpose of proving the truth of the statement made by the Cornish engineers, may with equal justice be charged with making false reports.

The reported "duty" is not necessarily the whole performance of the engine, the amount of which cannot always be obtained; it is, in fact, merely the weight of water lifted, multiplied by the height in feet to which it is raised, reduced to the number of pounds avoirdupoise raised one foot high, for every bushel of coals consumed, without reference to *friction*. Now as the friction of each engine, and the machinery worked by it, varies,—and as, although this friction has to be overcome, the amount of it is not reported, so the reported duty is not the whole performance of the engine; and, consequently, an engine which is reported as performing certain duty may, in fact, be doing as much work as another engine whose *reported* duty is greater.

The pumps in the mines in Cornwall are worked, and the water raised, as the engine goes "out of doors," the force of the steam is employed to raise the heavy pump rods; these rods are in many instances so weighty that without counterbalances, or, as they are termed in the county, "balance bobs," the engine would not be sufficiently powerful to raise them,—for instance, in some cases the pump rods are 150 tons in weight, which is equal to 336,000 lbs. Now the greatest load upon any engine reported in September last, was under 100,000 lbs. It is therefore necessary to have "balance bobs," or beams, one end of which is connected by a rod to the pump rod, and the other is weighted with iron as a counterbalance. These beams are in many instances as large as the beam of a 100 horse Boulton and Watt engine; it is evident that these cannot be worked without friction. In other cases the same engine not only

works the pump rods that are in the shaft immediately under the end of the engine beam, but also the pumps in distant shafts, by means of horizontal rods extending in some instances half a mile. These rods are supported either by pendulum rods or work on friction wheels; in these cases the friction must be great. It must also be borne in mind that there is more friction in a small cylinder, in proportion to its area, than in a large one, and, in fact, in all the bearings and working parts of the engine,—the power increasing as the squares of the diameters, while the friction increases as the diameters, directly. There are other sources of friction, but the above examples will be sufficient to prove that, although there appears a discrepancy in the reported duties of the Cornish engines, as *friction* is not taken into the account, it does not *necessarily* follow that an engine, whose *reported* duty is great, should be, in fact, superior to one whose *reported* duty is less.

In addition to this, the *reported* duty, of the same engine doing the same work, may vary 7 or 8 per cent. at different times, merely in consequence of the different quality of the coals supplied.

Particulars of the Cornish engines, shewing that they are not inapplicable for water-works purposes:—

First—The steam is raised to about 40 lbs. pressure upon the square inch, and the admission of it into the cylinder is cut off when the piston has travelled one-third, one-fourth, one-eighth, or even one-tenth of the length of the stroke, according to the work to be done, and during the remainder of the stroke the expansive power of the steam is exerted.

Second—The boilers are tubular, in some instances having an internal tube, *b b*, and a feed tube, *c c*, as represented in the accompanying drawing; in other instances these tubes are not introduced. I consider their introduction an improvement; the quantity of surface of the boiler exposed to the action of the fire, or heat of the flues, in proportion to its cubic contents of water, as compared with the Boulton and Watt boiler, is as 60 to 37, or as 3 to 2 nearly.

Third—All those parts of the boilers, cylinder, and pipes containing steam which are exposed to the air in most engines, are in the Cornish engines completely cased with a non-conducting material, which, in fact, renders the engine and boiler houses, where this system is carried to its full extent, as cool as the inside of a dwelling-house where there are only ordinary fires. Very little heat is lost when the engine stands still for twelve hours, and if it is necessary to start it during the night, or in case of emergency, scarcely any time is lost in

raising the steam, and one-fourth the fuel only is required after the engine has been standing all night; whereas, in the common engines and boilers, where every vessel containing steam is much exposed, it takes from twenty minutes to half an hour, firing hard, to raise the steam.

Fourth—The steam and exhausting valves are (what are termed in the county) "double beat valves;" they may be said to combine the advantages of the circular and slide valves, although not constructed like either; the effect is, however, that a man, who would not have strength to raise the valves of a 36 inch cylinder made according to the ordinary construction, may with perfect ease work the valves of an 80 inch cylinder, as made in Cornwall; the exhausting valves and the pipes leading to the condenser are made of much greater area than ordinarily.

Fifth—The length of the stroke is greater, and the number of strokes per minute fewer, than in other engines.

Sixth—The water is raised by a solid plunger working through a stuffing box, instead of a packed piston or bucket, so that, the packing being external, any leakage is detected immediately, without the delay attendant upon examining and fresh packing the ordinary packed pistons; and the pump may thus be made always to do its full duty, instead of, as is frequently the case, the water escaping by the piston when the packing becomes imperfect, or through bad valves when a bucket is used, and which cannot be detected until it increases to such an extent that the irregular working of the engine denotes it.

Seventh—The valves of the pump, instead of having their hinges in the centre, obliging the water to pass through a confined space between the valve and the side of the valve box, and lying almost flat upon their seats, making it necessary for them to rise much higher than would otherwise be required to deliver the quantity of water, and causing upon its descent so forcible a blow as to render it necessary to admit air under the valves, partially destroying the vacuum in preference to shaking the engine to pieces, and with openings through them of one-half or two-thirds the area of the pump barrel, rendering much greater power requisite to overcome the friction of the water in its passage through them,—instead of this arrangement, the valves are hung at the circumference of the circle and open in the centre, and the lower ones are fixed directly under the pump barrel;—they lie at a considerable angle to the horizon, so that a less rise of the valves is sufficient for the passage of the water, and the openings are made *equal* in area to the pump barrel. The effect is, that, without

the admission of air, as is absolutely necessary in the ordinary pumping engines, and which diminishes the quantity of water raised per stroke, although working under more than three times greater column of water, they make no blow of any consequence upon the return stroke.

Eighth—The cataract is used, by which the engine may be made to work from 1 to 12 strokes per minute, as may be required, consuming coals nearly in proportion to the number of strokes; the best rate however is about 5 or 6 strokes per minute. The cataract is peculiarly applicable to engines used in draining mines, where the work to be done increases in proportion as the working of the mine progresses; and also to engines for water-works where the demand increases every year, and the power must increase in proportion. To illustrate this, when one of the London water-works was first established, there were two engines of 30 horses' power, afterwards one of 20 horses' power, and afterwards one of 80 horses' power erected; the number of engines increasing as the demand for increased supply. Now if an engine upon the Cornish plan had been erected, which at 8 strokes per minute had been equal to 160 horses' power, then by working it 3 strokes per minute it would have been equivalent to the two 30 horse engines only, at 4 strokes to the two 30 horse and the 20 horse engines, and at 8 strokes equal to all of them. In this case one engine would have answered the purpose, and the saving that would have been made in engines, boilers, buildings, &c., wear and tear of machinery, labour, and current expenses, is evident.

Ninth—As the extent of pipes in a water-works district increases, the amount of friction must also increase, and the engine must work under a greater pressure; there must consequently be a greater load upon the pump. The ordinary engines would not be able to work under this increased load, and a smaller pump must be used; but as this would not give a sufficient quantity of water a new engine must be erected, and this has been the case hitherto; whereas, in a Cornish engine, by increasing the pressure of steam, or by working a less proportion of the stroke by the expansive force of the steam, this increase of expense may be much longer deferred.

Tenth—The Cornish engines, in which the before named arrangements have been adopted, do about three times more work, with the same quantity of fuel, than the common water-works pumping engines. As this has, however, been declared impossible, I will endeavour to prove the contrary by a comparison of the two engines.

The common water-works engine is worked with steam at a pressure generally of two and a half or three pounds above the pressure of the atmosphere; the admission of steam is not cut off until the piston has made three-fourths or seven-eighths of its stroke, and the principal object in view in cutting it off at all is to make the danger of the piston travelling too far, and the chance of breaking the bottom of the cylinder, beam, or parallel motion, less.

On the 18th of February last, I tried the power of an engine upon this construction; the experiment lasted one hour, and 469 lbs. of good Holywell Main large coals were used. The diameter of the cylinder was 60 inches, length of stroke 7 feet 9 inches; the engine made 869 strokes in the hour, or 14.48 strokes per minute; the pressure of steam was $2\frac{1}{2}$ lbs. per square inch above the pressure of the atmosphere, which was $14\frac{3}{4}$ lbs.; the vacuum in the condenser equal to $13\frac{1}{4}$ lbs.; the diameter of the pump was 27 inches, the length of the stroke 7 feet 9 inches, the pressure upon the pump piston equal to a column of water of 115 feet in height, load upon pump piston 28,577 lbs., equal to 10.1 lbs. pressure per square inch of the steam piston; as the pressure of the steam, minus $1\frac{1}{2}$ lb. for imperfect vacuum in the condenser, was $15\frac{3}{4}$ lbs., the friction of the engine must have amounted to 5.65 lbs. per square inch.

The steam used in the hour may be found thus:—the area of cylinder was 19.63 square feet, and the steam was cut off at 1 foot 3 inches from the end of stroke, making the length of stroke for the dense steam 6 feet 6 inches, which, multiplied by the area, gives 127.6 cubic feet per stroke, add $\frac{1}{10}$ for loss of steam per stroke in the vacancies of the cylinder, making a total of about 140 cubic feet of steam per stroke, which, multiplied by the number of strokes per hour, (869×140,) is equal to 121,640 cubic feet of steam, generated under a pressure of 35.2 inches of mercury, at a temperature of about 222° Fahrenheit.

The "duty" performed was 34,467,052 lbs. raised 1 foot high with a bushel, or 84 lbs. of coals.

The power of the engine during the time of trial was $(\overset{\text{lbs. load.}}{28{,}577} \times \overset{\text{stroke.}}{7.75} \times \overset{\text{strokes per min.:}}{14.48} \div 33{,}000)$ equal to 97.2 horses' power.

The steam used was equal to 1251 cubic feet per hour per horses' power, to produce which, at a temperature of 222° Fahrenheit, would require about

0.856 cubic foot of water, and to convert this quantity of water into steam at 222°, it *required*, 4.82 lbs. of coals.

Now supposing the admission of steam was cut off when the piston had travelled one-sixth of its stroke, the operation of its expansion, and the pressure at different stages, and mean pressure of the whole, will be seen by the following Table.

				lbs. pressure per square inch.
During $\frac{1}{6}$th	of the stroke	dense steam was admitted at a pressure of		17.25
At $\frac{2}{6}$	ditto	the steam had expanded to twice its volume, and the pressure was reduced to		8.62
At $\frac{3}{6}$	ditto	ditto	three times	5.75
At $\frac{4}{6}$	ditto	ditto	four times	4.31
At $\frac{5}{6}$	ditto	ditto	five times	3.45
At $\frac{6}{6}$	ditto	ditto	six times	2.87
				6)42.25
			Mean pressure per square inch	7.04 lbs.

If the steam had worked dense throughout, the pressure would have been 17.25 lbs. throughout, but 6 times the quantity of steam would have been required; whereas, with one-sixth the quantity of steam, the mean pressure is 7.04 lbs. per square inch, shewing that as the quantity of fuel required is in proportion to the steam generated, by working the engine thus expansively the effect is as 2.4 to 1.

If, however, the steam was to be generated under no higher pressure than 17.25 lbs. per square inch, it would be necessary to have the area of the steam cylinder 2.4 times greater than the one hereinbefore mentioned, to raise the load; that is to say, a cylinder of nearly 93 inches in diameter, with 7.04 lbs. pressure per square inch, instead of a cylinder 60 inches with $17\frac{1}{4}$ lbs. pressure per square inch. As this would obviously be disadvantageous, inasmuch as there would be a great increase of friction, the practice of using steam of higher temperature, say from 35 lbs. to 40 lbs. above the pressure of the atmosphere, has been adopted in Cornwall. In fact, the general dimensions for a Cornish engine to do the work hereinbefore stated, would probably have been as follows, viz.

Diameter of cylinder	57 inches.
Length of stroke	10 feet.
Number of strokes per minute	7
Diameter of pump piston	34 inches.
Length of stroke	10 feet.
Load on pump piston	45.805 lbs.
Load per square inch on steam piston	18 lbs.

In addition to the foregoing, which only shews the advantage to be 2.4 instead of 3, as I have before stated it to be, there is a very considerable saving in fuel in consequence of the casing, which saving is of course greater in proportion in engines where steam of a high temperature is used; and there is also less friction, in consequence of the slow motion of the engine, and from the other causes already stated, which, in my opinion, are fully equal to make up the difference. It is hardly necessary to observe here, that the more the steam is worked expansively the greater is the proportional advantage.

The principle of expansion is not *new;* it is the extent to which it has been carried, especially of late years, by the successful adoption of steam at a higher temperature than is used in the common condensing engine, which is new.

The late Mr. Watt took out a patent in 1782 for working steam expansively, and in his specification, dated March 12th, 1788, he says, "My new improvement in steam or fire engines, consists in admitting steam into the cylinder of the engine only during some certain part or portion of the descent or ascent of the piston, and using the elastic forces wherewith the said steam expands itself in proceeding to occupy larger spaces as the acting powers on the piston, through the other parts or portions of the length of the stroke of the piston."

He then shews, that if steam of 14 lbs. pressure is admitted into a cylinder, and cut off at one-fourth of the length of the stroke, that at half the stroke the pressure is reduced to 7 lbs.; at three-fourths of the stroke to $4\frac{2}{3}$ lbs.; and at the end of the stroke the steam would be reduced to $3\frac{1}{2}$ lbs., or one-fourth of its original power. He then shews that the sum of all these powers is greater than 57-hundredth parts of the original power multiplied by the length of the stroke, and consequently, that one-fourth the steam, thus used, produces

more than half the effect that four times the quantity would have produced if worked dense through the whole stroke.

He then says, "consequently, the said new or expansive engine is capable of easily raising columns of water, whose weights are equal to 5 lbs. on every square inch of the area of its piston, by the expenditure of only one-fourth the contents of the cylinder of steam at each stroke."

He had previously shewn that the engine working dense steam might be loaded to 10 lbs. per square inch of the area of the piston.

And lastly, he says, "and though, for example, I have mentioned the admission of one-fourth of the cylinders full of steam, as being the most convenient, yet any other proportion of the content of the cylinder will produce similar effects, and in practice I actually do vary the proportions as the case requires."

The casing of the cylinders, boilers, and steam-pipes is not new either, but I have never seen it carried to the same extent as it is at present in Cornwall.

Great and deserved credit is due to the perseverance, energy, and ingenuity of the Cornish engineers for bringing the expansive engine to the state that it now is, and for the daily improvements which, although taken separately may appear trivial, are in the aggregate of great importance.

I will conclude this portion of my observations by referring you to the printed Report of the public trial to which the Fowey Consols engine before mentioned has been exposed, in which it is stated, that the engine raised above 125 millions of lbs. one foot high, with 94 lbs. of coals, or nearly 112 millions with 84 lbs., or an imperial bushel. This is the greatest performance of any engine; and the engineers, Messrs. Petherick and West, cannot fail to receive the credit they so richly merit.

Although it is admitted by some engineers in London, that the reports from Cornwall may be true, and that water may be raised out of the *mines* at the expense of power reported, nevertheless, they assert that it is not applicable to water-works purposes, on account of the variation in the pressure.

That there is a variation in the pressure where the water is forced into the pipes directly from the engine is certain, and it must be dependent upon the quantity of water drawn from the mains by the tenants, and as this varies, so the pressure must vary—the variation is either not very great, or is periodical; thus the pressure during the day is greater than at night, and during summer

greater than in winter. In either case, the increased pressure arises from the circumstance of a greater quantity of water having to be forced through the same pipes in a given time; consequently, the velocity must be greater, and as a matter of course the friction, which increase of friction must be overcome by increased power. If the only variation was a periodical one, and at each period the pressure was steady, then reservoirs at different altitudes, to suit the different pressures, would supply the district as well as a steam engine; (even this position has been disputed;) but as at every stroke of the engine there is a slight variation, not amounting, however, during any of the periods before named to more than 5 or 6 feet, then, as the mean difference is $2\frac{1}{2}$ feet, and in case of a reservoir it would be necessary to have its altitude equal to the greatest pressure, there would be a loss amounting to the difference between the mean and the greatest altitude. It should be observed, that the *greatest* portion of the metropolis supply is from summit reservoirs.

Supposing that a Cornish engine could not be worked in the same manner as a London water-works engine, which, however, is not the case, and that it were necessary to work it under a fixed pressure, varying, however, at *given* periods, the loss, as before shewn, is trifling. Suppose it to be $2\frac{1}{2}$ per cent.; or taking the variation at 20 feet, instead of 5 feet, the loss would then be 10 per cent.; the gain, however, by adopting the Cornish engine, is 300 per cent.

There would, however, be an advantage in working either a Cornish or a London pumping engine under a fixed pressure instead of a variable one, and much less danger; for in all single engines, working under a pressure that varies, and where from the great extent of mains and services there is great liability to accident from the bursting of pipes, or sudden shutting off an important main by accident or design, the danger of the piston travelling too far, and thereby breaking the beam, or the cylinder bottom, is very great, and the only safeguard is the vigilance of the engine-keeper, who, if he is constantly watching, may take the engine " in hand," in case of a sudden variation in its speed, and thus prevent the accident which might otherwise have disabled the engine. This is not by any means a hypothetical case.

It would therefore be the safest plan to work the engine under a fixed load, even at the loss of a little power, if at the same time the liability to accident was rendered infinitely less.

In most cases, therefore, where the pressure under which the engine works is known, *and it ought to be known*, I should recommend the adoption of a standpipe, the water rising from the engine in one pipe, and flowing over either at the top, or through communicating pipes, at any level required, into the descending pipe communicating with the mains in the district. The engine might then work under a regular load; any fracture of the pipes in the district would not affect the engine; its only liability to accident being from the fracture of one leg of the standpipe, which of course could be provided against by extra strength of materials.

Although I have shewn how (upon the supposition of the variation in pressure being an objection to the application of the Cornish engine to water-works purposes) the supposed difficulty may be overcome, I by no means intend to allow that the engines in Cornwall are not subject to chances of as great and even greater variation; for if any valve breaks, which is very likely to happen where there are so many pumps at work, if the water at any time fails, and air is suddenly admitted through the suction-pipes, &c., &c., in all such cases, the resistance to the power of the engine is reduced, and if the parts of the engine were not made strong enough to resist the force of a sudden blow, fracture would take place; but they are generally, and ought always, to be strong enough.

In conclusion, I beg to observe, that if the Cornish engines do the work that it is stated they do, and if they are applicable to water-works purposes, of both of which I have no doubt, then the saving is most important; for supposing instead of *three* engines, consuming 3000 tons of coals per annum, *one* could be erected doing the work of the three, and only consuming 1000 tons, assuming the price of coals delivered to be 18*s*. per ton, the saving in coals alone, without reference to the savings in the reduced number of engine-keepers and stokers, the current expenses of one engine instead of three, the wear and tear of machinery and buildings, would be £1800 per annum.

Nov. 4, 1835.

XII. *Description of the plan of restoring the Archstones of Blackfriars Bridge. By* JAMES COOPER, *A.Inst.C.E. Communicated in a letter to the Secretary.*

FROM the perishable nature of the material with which even the largest bridges were built, before the use of granite became so common as it has of late years in the more important structures of this kind, the best plan of repairing parts falling to decay, is a point of some consequence. With a view to contribute towards the stock of information on the subject, I beg to offer to the Institution the accompanying drawing (plate no. XXIV), showing the mode that has been adopted by Messrs Walker and Burges, of restoring the archstones of Blackfriars Bridge, with the following observations in explanation of it.

The decayed part is first cut out for the whole height of the course, to the depth of 15 inches generally, but in faulty places sometimes as much as 2 feet, and never in shorter lengths than a foot; and the beds and sides of the opening being dressed fair, moulds or templates are fitted into it to get the correct shape for the new work.

The stone is inserted in two thicknesses, the lower of which, *a*, is dovetailed or radiated rather more than the original archstone, and the upper, *b*, slightly tapered like a wedge, to enable it to be driven; the dimensions of the two when put together making up the size of the cavity. Circular holes are sunk opposite each other in the adjoining beds of the two pieces to receive the dowel *c*, that in the lower part, *a*, being half the length of the dowel deep, while the corresponding hole in the part *b*, is deep enough to receive the dowel completely, so that when deposited in the hole, the dowel may offer no obstruction to getting the stone in; and from the bottom of these holes, openings, *d*, *e*, of about $\frac{3}{4}$ inch diameter are drilled to the chamfers on the face of the joints.

The dovetailed stone, *a*, is first set in mortar, and brought to a bearing on its bed, by wedging applied in the place afterwards to be occupied by the other half, *b*; which is next covered with mortar on the beds and joints, and driven in by wooden beetles until the circular holes in the beds come opposite each other, when, the cord *d* having been disengaged, the dowel *e* (held by it in the

hole in the bed of the upper stone *b*) is drawn or pushed half its length into the stone *a*. Should the new stone be sufficiently in contact with the old work, which the sound from the beetle readily denotes, and be otherwise properly driven, mortar is rammed down the hole *d*, so as to surround the dowel and keep it in its proper place. The cord *e* for drawing the dowel home runs in a groove in the bed of the stone *a* from the dowel hole to the face of the archstone, and sometimes when it is not brought into action the dowel is pushed with a jointed piece of iron wire inserted through the opening *d* in the upper stone.

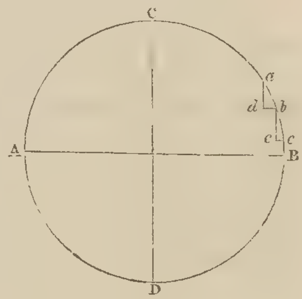
The wedge-formed stones, *b*, are usually 12 inches thick on the face, tapering off half an inch at the depth of 15 inches, and run from a foot to 2 feet 6 inches long, which they seldom exceed, as when thicker or longer they are found unwieldy to drive. These limitations are not, however, required in the dovetailed stone *a*, which is put in in as long lengths as are supplied, and its thickness is regulated by the cavity to be filled, the other stone, *b*, being, as has just been stated, generally uniform in this dimension. The dowels, which are of Craigleith stone, are 5 inches long and 3 inches diameter in the middle, diminishing to $2\frac{1}{2}$ inches at the ends.

When the new stone is inserted, as has been described, and the dowel secured in its place, it is evident that neither half can drop out, and that on the hardening of the mortar, though *two* pieces, they become for practical purposes *one* archstone. But while the work is in progress, and before the stone *b* is put in, the dovetailed stone *a* has a tendency to slide out, which is sometimes met by strutting from the scaffolding, or by leaving a small tenon on the under side of the new stone fitting into a mortise in the masonry beneath; but within six or eight courses on either side of the crown of the arch, and in other places, when a considerable length has been taken out, a joggle *f*, 4 inches long by $2\frac{1}{2}$ inches square, is inserted at each end of the new work, or in the case of a very short stone at one end only, being let from the upper bed of the stone *a* diagonally into the vertical joint between the new and the old work, so that half is in one and half in the other.

So far as I am aware, the above scheme is new, and it seems fully to meet the difficulties of the case; the new stones filling completely the hollows left by the old ones cut out, which from the radiation of the joints in an arch they could not if put in as one piece, and so giving a perfect bearing between the original and the restored work, while the whole is secured without injury to the adjoining masonry by external wedging or otherwise.

XIII. *On the Force excited by Hydraulic Pressure in a Bramah Press; the resisting Power of the Cylinder, and Rules for computing the Thickness of Metal for Presses of various Powers and Dimensions.* By PETER BARLOW, F.R.S., &c., *of the Royal Military Academy.*

I AM not aware that any of our writers on mechanics have investigated the nature and amount of the circumferential strain which is excited in an hydraulic cylinder by a given pressure on the fluid within; it will be proper, therefore, first to examine this question: viz., to find the circumferential strain on a ring of any material, arising from an internal pressure.



Let *ab*, *bc*, be any small elementary part of the circumference, which may be taken as right lines, and let the pressure on each of them be called *p*, which, being proportional to them, may be represented by the elements themselves, *ab*, *bc*, these being perpendicular to the direction in which the pressure acts. Resolve these pressures or forces into two rectangular forces, *ad*, *db*, *be*, *ec*, of which, *ad* and *be* will represent forces acting perpendicular to their direction or parallel to AB, and *db* and *ec* forces parallel to DC. Confining ourselves at present to the former, if we conceive the semi-circumference DBC to be divided into its component elements, it is obvious that the sum of all the forces acting parallel to AB, will be equal to the sum of all the perpendiculars, *ad*, *be*, or to the whole diameter DC. That is, the sum of all the forces acting parallel to AB, will be to the sum of all the forces or pressure on the semi-circumference DBC, as the diameter to the semi-circumference. But the pressure on the semi-circumference is equal to the number of inches in the same, multiplied by the pressure per square inch, consequently the force or pressure exerted parallel to AB, will be equal to the inches in the diameter, multiplied by the pressure per square inch, the ring being here supposed, for the purpose of simplification, only an inch deep. But to resist this pressure, we have the two thicknesses of the ring at D and C; therefore the direct strains on the circumference at any one point, as D, will be equal to the pressure of the fluid per square inch, multiplied by the number of inches in the radius.

We should come to the same result more simply, but perhaps not so satisfactorily, by conceiving a section passing through the diameter DC; then it follows that the pressure on this section, which is directly resisted at D and C, is equal to the number of square inches in the section, multiplied by the pressure per square inch. Therefore the strain on D or C singly, is equal to the pressure per square inch multiplied by the inches in the radius; the same as above.

TO INVESTIGATE THE NATURE OF THE RESISTANCE OPPOSED BY ANY GIVEN THICKNESS OF METAL IN THE CYLINDER OR RING.

It would appear at first sight, that having found the strain at D and C, it would only be necessary to ascertain the thickness of metal necessary to resist this strain when applied directly to its length; this, however, is by no means the case, for if we imagine, as we must do, that the iron, in consequence of the internal pressure, suffers a certain degree of extension, we shall find that the external circumference participates much less in this extension than the interior, and as the resistance is proportional to the extension divided by the length, according to the law *ut tensio sic vis*, it follows, that the external circumference, and every successive circular laminâ, from the interior to the exterior surface, offers a less and less resistance to the interior strain: the law of which decrease of resistance it is our present object to investigate.

In the first place, it is obvious that whatever extension the cylinder or ring may undergo, there will be still in it the same quantity of metal, or, which is the same, the area of the circular ring, formed by a section through it, will remain the same, which area is proportional to the difference of the squares of the two diameters.

Let D be the interior diameter before the pressure is exerted, and $D+d$ its diameter when extended by the pressure. Let also D' be the external diameter before, and $D'+d'$ the diameter after the pressure is exerted; then from what is stated above it follows, that we shall have

$$D'^2 - D^2 = (D'+d')^2 - (D+d)^2$$

$$\text{or, } 2D'd' + d'^2 = 2Dd + d^2$$

$$\text{or, } 2D' + d' : 2D + d :: d : d'$$

or since d' and d are very small in comparison with D' and D, this analogy becomes $D' : D :: d : d'$. That is, the extension of the exterior surface is to that of the interior as the interior diameter to the exterior.

But the resistance is as the extension divided by the length, therefore the resistance of the exterior surface is to that of the interior as $\frac{D}{D'} : \frac{D'}{D}$ or as $D^2 : D'^2$. That is, the resistance offered by each successive lamina, is inversely as the square of the diameter, or inversely as the square of its distance from the centre; by means of which law the actual resistance due to any thickness is readily ascertained.

Let r be the interior radius of any cylinder, p the pressure per square inch on the fluid, t the whole thickness of the metal, and x any variable distance from the interior surface. Let also $rp=s$ represent the strain exerted at the interior surface, according to the principles explained in the preceding part of this paper. Then by the law last illustrated we shall have,

$(r+x)^2 : r^2 :: s : \frac{r^2 s}{(r+x)^2}$ for the strain at the distance x from the interior surface;

and consequently $\int \frac{r^2 s dx}{(r+x)^2}$ + Cor. = the sum of all the strains, or the sum of all the resistance. This becomes, when $x=t$, $R=r^2 s\left(\frac{1}{r}-\frac{1}{r+t}\right)=s\,\frac{rt}{r+t}$.

That is, the sum of all the variable resistances due to the whole thickness t, is equal to the resistance that would be due to the thickness $\frac{rt}{r+t}$ acting uniformly with a resistance s, or rp.

APPLICATION OF THIS RULE FOR COMPUTING THE PROPER THICKNESS OF METAL IN A CYLINDRIC HYDRAULIC PRESS OF GIVEN POWER AND DIMENSIONS.

Let r be the radius of the proposed cylinder, p the pressure per square inch on the fluid, and x the required thickness: let also c represent the cohesive strength of a square inch rod of the metal.

Then from what has preceded it appears, that the whole strain due to the interior pressure will be expressed by px, and that the greatest resistance to which the cylinder can be safely opposed is $c \times \frac{rx}{r+x}$: hence when the strain and resistance are in equilibrio, we shall have

(1). $$rp=\frac{rx}{r+x}\times c$$

or $pr+px=cx$

whence $x=\frac{pr}{c-p}$ (the thickness) sought.

Hence the following rule in words for computing the thickness of metal in all cases; viz., multiply the pressure per square inch by the radius of the cylinder, and divide the product by the difference between the cohesive strength of a square inch rod of the metal and the pressure per square inch, and the quotient will be the thickness required.

At present we have only considered the circumferential strain: to find the longitudinal strain, we have to multiply the area of the piston by the pressure per inch; while the resistance in this direction will be equal to the cohesive power of the metal multiplied by the area of the transverse section of the cylinder; so that when these are equal to each other we shall have

$$(2) \qquad 3{\cdot}1416\, r^2 p = 3{\cdot}1416\,(2rx + x^2)\, c$$

$$\text{which gives } x = r\left\{\sqrt{\left(\frac{p}{c}+1\right)} - 1\right\}$$

And it is obvious that whichever of these two values of x, viz. (1) or (2), is the greatest, is the one which must be adopted. It will appear, however, that in all practical cases the former is the greater; for it is only when p exceeds c that the latter value of x can be ever equal to the former. Let us, for example, find the relative values of p and c, when these values of x are equal to each other, by making

$$\frac{rp}{c-p} = r\left\{\sqrt{\left(\frac{p}{c}+1\right)} - 1\right\}$$

$$\text{this gives } \frac{p^2}{(c-p)^2} + \frac{2p}{c-p} = \frac{p}{c}$$

$$\text{or} \qquad p^2 c + 2pc\,(c-p) = p\,(c-p)^2$$

$$\text{or} \qquad p^2 - pc = c^2$$

$$\text{whence} \qquad p = c\left(\tfrac{1}{2} \pm \tfrac{1}{2}\sqrt{5}\right)$$

That is, these two values of x can only be equal to each other when p exceeds c in the ratio of $(\frac{1}{2} \pm \frac{1}{2}\sqrt{5}) : 1$; which is an impracticable pressure; for it is obvious from the first value of x, that no thickness will be sufficient to resist an internal pressure which exceeds (per square inch) the cohesive power of a square inch rod of the metal; a result which at first sight appears to be paradoxical; but it will be observed that, with such a pressure, the interior surface will be fractured before the other parts of the metal are brought into action.

It will therefore be sufficient to attend wholly to the first expression; and here it may be observed that x and r, with the same pressure and cohesive power, being always in the same ratio, we may reduce the rule for finding the thickness of metal to the following tabulated form, in which it will only be

necessary to multiply the number standing against any pressure by the internal diameter of the cylinder or piston for the thickness required.

The cohesive strength of cast iron, according to experiments made at Capt. Brown's manufactory, is 7·26 tons per square inch; but his machine underrates its power 8 per cent.; (see my Essay on the Strength of Wood and Iron, page 258, 2d edition;) this added, gives us 7·86 tons, or 17,612 lbs., per square inch.

Mr. Rennie gives two results for the cohesive power of cast iron, viz.,

1st	= 18,656
2d	= 19,072
My experiment . . .	= 17,612
Mean	= 18,685

We may, therefore, without sensible error, call the cohesive power 18,000 lbs. per square inch.

The cohesive power of the best gun-metal is given by Mr. Tredgold, in his edition of Buchanan's Treatise on Mill Work, 36,000 lbs. per square inch, and that of lead, 3328 lbs. per square inch; and with these numbers I have computed the following thickness for pipes of an inch diameter, for the various pressures given in the Tables, and which will apply to any other case by multiplying the tabular numbers by any given diameter.

TABLE FOR COMPUTING THE THICKNESS OF CAST IRON PIPES AND CYLINDERS.

Cohesive Strength of Cast Iron, 18,000 lbs.							
Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.
1000	·0294	2000	·0625	3000	·1000	4000	·1428
1100	·0325	2100	·0660	3100	·1040	4500	·1666
1200	·0357	2200	·0696	3200	·1080	5000	·1922
1300	·0388	2300	.0732	3300	·1122	5500	·2200
1400	·0421	2400	.0769	3400	·1164	6000	·2499
1500	·0454	2500	·0806	3500	·1207	6500	·2827
1600	·0487	2600	.0844	3600	·1250	7000	·3181
1700	·0521	2700	·0883	3700	·1293	7500	·3570
1800	·0555	2800	·0921	3800	·1337	8000	·4000
1900	·0590	2900	·0959	3900	·1382	8500	·4462

TABLE FOR COMPUTING THE THICKNESS OF GUN-METAL CYLINDERS; APPLICABLE ALSO TO GUNS AND MORTARS.

Cohesive Strength of Gun-Metal, 36,000 lbs.							
Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.
1000	·0143	2000	·0294	3000	·0454	4000	·0625
1100	·0157	2100	·0309	3100	·0471	4500	·0714
1200	·0172	2200	·0325	3200	·0487	5000	·0806
1300	·0187	2300	·0341	3300	·0504	5500	·0901
1400	·0202	2400	·0357	3400	·0521	6000	·1000
1500	·0217	2500	·0372	3500	·0538	6500	·1102
1600	·0232	2600	·0388	3600	·0555	7000	·1207
1700	·0247	2700	·0405	3700	·0572	7500	·1315
1800	·0263	2800	·0421	3800	·0590	8000	·1428
1900	·0278	2900	·0438	3900	·0607	8500	·1543

TABLE FOR COMPUTING THE THICKNESS OF LEAD CYLINDERS, WATER PIPES, ETC.

Cohesive Strength of Sheet Lead, 3320 lbs.					
Pressure.	Thickness.	Pressure.	Thickness.	Pressure.	Thickness.
5	·00075	100	·0155	1100	·2477
10	·001510	200	·0320	1200	·2830
20	·003030	300	·0496	1300	·3217
30	·004559	400	·0684	1400	·3645
40	·006097	500	·0886	1500	·4120
50	·007645	600	·1102	1600	·4651
60	·009202	700	·1335	1700	·5246
70	·010769	800	·1587	1800	·5921
80	·012345	900	·1859	1900	·6690
90	·013931	1000	·2155	2000	·7575

For a pressure not found in any of the above Tables, it will be sufficiently correct to use the following proportion, viz.:

As the difference of the two tabular pressures, between which the given pressure falls; is to the difference between the corresponding tabular thickness,

so is the difference between the lesser tabular pressure and the given pressure, to the difference between the lésser tabular thickness and that required. Suppose, for example, the thickness for a cast iron cylinder were required for a pressure of 3650 lbs.

Pressure . .	3700	Thickness . .	·1293
Do. . . .	3600	Do. . . .	·1250
Difference . .	100	Difference . .	·0043

100 : ·0043 :: 50 : ·0021

Therefore . . ·1250
·0021
1271 the thickness sought.

As another example of the use of the Table, let the thickness of a cast iron cylinder be required, that will bear a proof pressure of 3 tons per circular inch, the interior diameter being 12 inches.

Here $\frac{3 \text{ tons}}{\cdot 7854} = 3\cdot 819$ tons or 8554 lbs. per square inch. Call this 8500 lbs.; then, by Table I., the thickness for an inch cylinder is ·4462, consequently $4462 \times 12 = 5\cdot 3544$ inches, the thickness required.

It will of course be understood that the thicknesses given in the Table are the least that will bear the required pressure, and that, in common practice, presses ought not to be warranted to bear above one third the pressure given in the Table, unless it should appear that the estimated cohesive power of cast iron is too little; if this actually exceed 18,000 lbs., a corresponding reduction may be made in the computed thicknesses.

XIV.—*An Account of some Experiments on the Expansion of Water by Heat. By the late T. Tredgold, M.Inst.C.E.*

The expansion of water, by increase of temperature, is one of those experimental subjects that has not received the degree of attention its importance would lead us to expect; but, as even the smallest addition to any part of knowledge contributes towards its increase, I have ventured to send this mite for the consideration of the members of the Institution.

I began by a series of trials with a thermometer, containing water instead of mercury, to find the point at which the volume of water is a minimum, by cooling successively down to 32° with snow and water, and observing the decrease of bulk, which continued till the temperature was 40°; the rise again was then sensible. In like manner by cooling, the decrease continued till the temperature was about 39°, when the rise became sensible. So small and uncertain, however, was the rate of increase or decrease, that we may practically estimate 40° as the temperature corresponding to the maximum density of water.

Having marked the tube at the point when the temperature was 40°, and also another point within the range of the tube, I divided the distance between these, into four equal parts. With this precaution I immersed the water thermometer, and a mercurial one, in a vessel of hot water, and as it cooled compared the temperatures as the water contracted to each division on the tube. The mean of several trials was as follows:

Temp.	112°	4th or upper division.
—	104°	3d.
—	90°	2d.
—	74°	1st division.
—	40°	maximum density.

I intended to repeat the trials and to correct these numbers; but the cold weather commenced, and instead of attending to the higher degrees of heat, my attention was directed to the lower ones. The bulb of the thermometer was immersed in a mixture of snow and salt, and a mercurial one placed beside it, but I found the two were not alike affected by the mixture; the water thermometer rose rapidly till it arrived at, or very near to the third division on the tube, when it exploded. At the moment of explosion, the central part

of the mass of water, and that in the tube were both perfectly fluid, and the fragments of the bulb were lined with a thin coat of ice, beautifully crystallized. The fractured bulb presented a singular appearance, the whole being cracked into very fine gores, somewhat less than one-twentieth of an inch in breadth at the middle, and exceedingly regular.

The temperature of a mixture of snow and salt is $-5°$, or 5 degrees below zero; hence, if the expansion below 40° had been the same as far above 40° the thermometer ought not to have risen quite to the second division; but, as it rose very nearly to the third division, it seems that the expansion below 40° is much greater than at a corresponding number of degrees above 40°; and that the common opinion is not quite correct in this respect.

I have not had leisure to follow up these trials, for they consume an immense quantity of time; but from those made by others, and checked by my own, I have deduced a formula for calculating the expansion at any temperature.

If we consider the force with which matter resists the entrance of heat to be inversely as the square of the distance of its elementary atoms; then, the bulk being as the cube of the distance, the resistance to heat will be inversely as the square of the cube root of the volume, and the increments of expansion by heat directly as the $\frac{2}{3}$ power of the volume. The sum of the increments will, therefore, be as the $\frac{5}{3}$ power of the volume, and the equation must give zero at 40°; hence it will be $A\ (t-40°)^{\frac{5}{3}}$ = the expansion, where A is a coefficient to be found by experiment, and t denotes the temperature.

The calculation is easy enough by logarithms, for, $\log A + \frac{5}{3}\log\ (t-40)$ = log of the expansion; or $3\left(\frac{\log\ \text{expansion} - \log\ A}{5}\right) = \log\ (t-40°)$.

The formula in the last form applies to my experiment, and becomes $3\left(\frac{\log\ \text{expansion} + 3\cdot09555}{5}\right)$ = the $\log\ (t-40)$, the expansion at 112° being considered unity; hence the comparison is easy, and is as under.

Expansion.	Temperature by experiment.	Temperature by formula.
1	112°	112°
0·75	104°	100°
0·5	90°	87°
0·25	74°	71°
0·00	40°	40°

The coincidence is as near as we could expect, considering how difficult it is to insure perfect accuracy in the observations; but, before we proceed further in experiment, it is natural to ask how it will agree with others already made.

The expansion of water from 40° to 212° has been found to be 0·04333, its bulk at 40° being unity. By substituting this value in the formula, we find the coefficient A, and have the rule $\frac{5}{3}\log(t-40)+(-6\cdot910909)$, or its equivalent $\frac{5}{3}\log(t-40)-5\cdot089091=$ the log of the expansion.

The formula being in this case derived from a probable hypothesis, it is more likely to express the true expansion, than one made out merely to fit a short range of experiments. The absurd conclusions which may follow from an experimental rule are avoided; and that such conclusions do arise out of formulæ made to fit a particular set of experiments, we have an evidence in the case under consideration; for Dr. Young* has given a formula for calculating the expansion of water, which becomes negative when the temperature is 540°; indicating that water would decrease in bulk, by increasing its temperature above that point; this is a circumstance too improbable to guide us in any practical application of the formula.

The annexed Table shows the bulk and expansion for a few temperatures.

Temperature.	The expansion. By experiment.	The expansion. By formula.	Bulk by formula.	Temperature.	Expansion by formula.	Bulk.
40°	0	0	1·0000	400°	0·1484	1·1484
64°	0·00133	0·00162	1·00159	800°	0·5155	1·5155
102°	0·00760	0·00791	1·00791	1000°	0·7610	1·7610
212°	0·04333	0·04333	1·04333	1171°	1·0000	2·0000

In my own experiments, the formula was in defect in the temperatures between 40° and 112°; here it is in excess; the difference may arise from the expansion of the glass in my trials. According to this formula, water will expand to double its bulk at 40° by a temperature of 1171 degrees. What would be the force of the steam to confine it to the liquid state at that temperature? There is abundant scope for curious research in this matter: it is one where speculative opinion feels the want of experience.

I am not aware of there being any experiments on the expansion of water above the boiling point. When I find an opportunity, I intend continuing the

* Lectures on Natural Philosophy, Vol. II. p. 392.

series as I can, using something to colour the distilled water, for facility of observing; and I trust soon to be able to communicate some account of my progress *.

* It is not certainly known whether Mr. Tredgold ever followed out the consideration of this interesting subject; but, as he made no further communication thereon to the Institution, and his premature death took place soon after the date of this paper, it seems probable that his experiments were never resumed.

XV.—*On procuring supplies of Water for Cities and Towns, by boring. Communicated by Mr.* John Seaward, *M.Inst.C.E.*

A French gentleman of our acquaintance having recently addressed us upon a project of supplying the different towns of France with water, by means of boring in the earth, according to the method which has come lately a good deal into fashion in different parts of England, and thus having brought the subject under our mature deliberation; we offer the following remarks, which we were led to give in reply, with the hope that they may be found not altogether uninteresting to the Institution.

In the first place, as respects the project of furnishing water to the different towns of France by means of simply boring in the earth; if by this is intended that the various towns are to be supplied with water economically, for all domestic and manufacturing purposes, in the same abundant manner that it is furnished to the inhabitants of London and other towns of England, we must at once declare without any hesitation, that, as a general principle, the scheme will be abortive, and if attempted will infallibly end in loss and disappointment.

In stating thus explicitly our opinion, we do not wish to be understood as being anywise unfavourable to boring generally; on the contrary, as an art when employed under suitable circumstances, we know that it can be made, on various occasions, highly subservient to the wants of man, but we also know that with many persons, a very erroneous opinion prevails as to the economy, and other merits and advantages of the art.

The method of "simple boring," as it is called, is not adapted for all situations and places; it requires a combination of circumstances not generally met with: London and the surrounding district, wherein this art has been most successfully practised, is highly favoured in this particular; the stratum of soil is a bed of clay, varying from 100 to 200 feet thick, and is therefore very easily bored through. It is remarkable that the springs under the bed of clay produce the finest and most salubrious water, while those above the bed of clay produce water so impure as to be unfit even for the most ordinary purposes. It is therefore easy to conceive, that this method would here meet with the most favourable encouragement, but in districts where the same circumstances do not exist, there would not be the same inducement to follow it.

"Simple boring," is suitable only when the quantity of water required is comparatively small: thus if the object be to furnish a very superior water for a

nobleman's mansion, for a small village or neighbourhood, or even for a single manufactory, then this method is admirable, provided the circumstances are in any proportion as favourable as in the district which surrounds London; but if the question be to provide an abundant supply of water for a large town or populous city, then certainly in every case, the method of boring should, on the score of economy, be the last that ought to be resorted to for the purpose.

That the bowels of the earth contain springs of water in abundance, there can be no doubt; miners and colliers are aware of this fact to their cost and sorrow: but we know full well that those same springs, if they have sufficient natural force, must find their way to the surface of the earth somewhere, without any boring, and then form rivers and flowing brooks. Why then delve a great depth at an infinite expense, to procure that which we can generally obtain so readily and economically on the surface of the earth?

There is scarcely a city or town of any magnitude but what has some fine river or copious brooks in its immediate neighbourhood, these are the natural sources whence we should obtain our supply of water; but if the streams in the vicinity are so impregnated with deleterious matter, as to render the water unfit for domestic or manufacturing purposes, and if no ready method can be adopted for cleansing it, recourse should then be had to the water that falls from the heavens; tanks and reservoirs, (similar to those employed in feeding navigable canals,) should be formed in convenient situations, to receive the rain-water which falls on the adjacent hills: either of these means would furnish an abundant supply of this necessary element constantly and economically.

It is perfectly true, that a populous town may be so situated as to be at an inconvenient distance from any salubrious river or brook, whence to obtain water, and local circumstances may be such as to render it impossible or inexpedient to form in the vicinity tanks or reservoirs to collect the rain-water from the hills; in this case, there appears to be no alternative but that of obtaining a supply from the bowels of the earth: in such case, it will be necessary to sink very capacious wells or shafts to a great depth, with suitable pumps and steam-engines, to bring the water to the surface; and even then the supply may be so scanty as to render it necessary to drive (in various directions) horizontal levels or galleries from the bottom of the wells or shafts, in order to break in upon the springs which may exist at a distance; similar to the method practised in the salt-works of England, to obtain a copious supply of the brine;

but in such case to expect that by simply boring down into the earth, a plentiful supply of water can be obtained for the domestic and manufacturing purposes of a populous town, is to expect what rarely or never can be accomplished.

The modern plan of boring to obtain water has been, without any rational grounds, cried up as a new and wonderful discovery, but the truth is, that boring is an operation of great antiquity; the miner and collier make use of it in a variety of ways; and it has from time immemorial been a useful auxiliary to the well-digger; he employs this process to discover where springs of water exist. By this means he can at a comparatively small expense determine whether the situation is favourable or not for forming a well; at the same time he can ascertain the quality of the water when obtained, and the probable ultimate expense which must be incurred in order to secure a regular supply.

In some instances it has happened that in boring, from the cause just stated, the water has of its own natural force risen up through the hole, and flowed over the surface in considerable quantity, and thus, without much further trouble or expense, a tolerably copious supply has been obtained. This circumstance it is that has brought into favour the idea of depending on simple boring alone, as a regular systematic method of obtaining a supply of water; and it is but right to say, that the method, in many instances, has been remarkably successful; but it should be borne in mind, that the supply, copious as it is called, has scarcely in any one instance exceeded what would be required for a moderately extensive manufactory, or for the domestic use of a very small village; moreover, although considerable success has attended many of the experiments made to obtain water in this way, yet it is most certain that, as regards the obtaining of an abundant supply by the simple process of boring alone, in a majority of cases, the method has *completely failed;* and, after a very heavy and useless expense and loss of time has been incurred in these failures, recourse has at length been had, either *partially or wholly,* to sinking a well.

The most rational plan for obtaining a good supply of water from underground is, in the first place to sink a well to about half the depth at which it is supposed the spring of water exists: thus, if the spring is judged to be 100 yards below the surface, then the well may be made 50 yards deep; this being properly built up and secured, the engine erected, and suitable pumps fixed, the remainder of the depth to the spring may be pierced through by the process

of boring, and in this way a copious supply of water is frequently obtained, and as may be readily judged, the quantity of water obtained will vary according to the greater or less depth to which the well is formed; but at the same time it should be observed, that the deeper the well, the greater will be the expense of raising the water to the surface.

If necessary we could here enumerate a long list of losses, failures, and consequent disappointments, which have attended the process of boring, within our own observation; for the present, however, we shall confine ourselves to two instances.

About four years ago we erected, almost in the heart of the metropolis, a 14-horse condensing engine for a manufacturing purpose. As a good supply of water was wanted for that and other objects, the proprietor of the establishment thought he would obtain this necessary element on his own premises, and make himself independent of the water-companies. We recommended him to sink a well at once; but contrary to our advice, he determined to try the process of simple boring, the situation of his premises being judged very favourable for that purpose. A hole was consequently bored to about 100 yards deep, and after some labour and expense water was obtained, but the supply was so scanty as not to be half sufficient for the 14-horse engine; several attempts were made to remedy this but without effect; the hole was at length abandoned, and a well was then formed, though not so deep as it should have been; boring was then resumed to the depth of what was considered the main spring; pumps were put down the well, and water was again obtained; but even after all, the supply was barely sufficient for the engine. The result of this business was, that the proprietor after having his premises in confusion for nearly two years, in the end expended double as much money as would at once have formed a good productive well, and the interest of the money so expended is considerably more than he would have had to pay to any water-company for all the water he required for his engine and manufactory, besides losing a considerable portion of the power of his engine, which is expended in drawing the water to the surface.

Within a quarter of a mile of the above-described well was situated a brewery furnished with a similarly-constructed well, from which a considerable supply of water had previously been obtained; it is, however, worthy of remark, that no sooner did our engine commence drawing water from the new-formed well, than the brewers immediately lost a great part of the supply they

had previously been accustomed to derive from theirs; the consequence was, they were under the necessity of sinking it deeper, and of putting up more powerful pumps, in order to obtain their former supply.

We mention the above fact to shew that, although there is no question but it is possible to find a spring of water in almost any situation, yet the springs do not furnish that inexhaustible supply of water which some persons imagine; indeed a bare consideration of what is accomplished in mines and collieries must convince us of the truth of this fact; were the springs of that inexhaustible nature some pretend, not a single mine or colliery in the universe could be worked to any moderate extent whatever.

The second instance of failure in boring, which has happened in our own practice, we shall now proceed to relate. About twenty years ago a canal was cut in the neighbourhood of London which passes over a very hilly tract of land, and in the summer months there is great difficulty in obtaining a sufficient supply of water for the upper level. It is true the canal passes very near some copious brooks and streams, which with little expense or trouble might have been made available to supply every deficiency twenty times over; but from some circumstances the proprietors of the canal were not permitted to take advantage of these facilities, and as the rain-water they were enabled to collect from the hills was inadequate, they were under the necessity of resorting to the bowels of the earth to supply the deficiency. For this purpose, a large hole was bored down at the side of the canal, to a depth of two or three hundred feet, to what was understood to be the main spring: the water speedily rose and flowed over the surface: however, it was soon discovered, that the quantity obtained by this means was so very small as to be of no practical utility: a well of large dimensions was then sunk down about 80 feet, the boring still continuing to the original depth; pumps were fixed, and machinery worked by horses; the supply of water by this means was increased tenfold, but still was inadequate for the purpose required. We were then employed to erect a steam-engine with suitable pumps, &c., and the well was sunk to double the original depth; a much more copious supply was now obtained, and the navigation thereby greatly assisted; but after all, the expenses attending these works, and the pumping up the water from such a depth, and that too still inadequate in quantity, are evils of such a serious magnitude, that these joined to other circumstances attending this property, will probably before long cause the whole of the concern to be abandoned.

We could add many other instances of the total failure of what is called the simple boring system; of works begun and never finished to any useful purpose; of others pertinaciously carried on for four or five years, until the patience and the funds of the parties were alike exhausted; but we think enough has been stated above to prove to your satisfaction, how very uncertain has been this method of obtaining water. We think it right, however, to guard against the impression that boring for water is a bad system; on the contrary, allow us to repeat that we think most highly of it; but then only under proper management, and as a useful auxiliary to the sinking of capacious wells.

With respect to the project generally, of forming a regular establishment for the purpose of supplying water to the various towns of France, we have to remark, that there can exist no physical impediment to the accomplishment of the plan; there is no question but every town in France might be made to enjoy the same inestimable advantages possessed by the inhabitants of London and other towns of England; that is to say, a constant, abundant, and an economical supply of good water, for all purposes of domestic and manufacturing use; but of the three modes by which this can be accomplished, the one by boring or well-sinking is decidedly the most expensive, and the most uncertain in the final results.

XVI.—*Some Account of several Sections through the Plastic Clay formation in the vicinity of London. By Mr.* William Gravatt, *F.R.S., M.Inst.C.E.*

TRING HILL, HERTS.

A boring for water for the Grand Junction Canal commenced at 25 feet below the summit level of the hill near Marshcroft Bridge.

Chalk . . .	20 feet.	
Hard blue clay .	30	
Blue stone . .	4.	At 54 feet the water rose to the top, and ran over 1300 cubic feet in 24 hours.
Hard blue clay .	47	
	101	feet—no more water than at 54 feet.

The boring discontinued in Nov. 1827.

A second boring in the same hill commenced 20 feet from the summit level.

Chalk . . .	30 feet.	
Hard blue clay .	34	
Blue stone . .	4.	Water rose up. The stone required punching before using the auger.
Blue clay . .	82	Strata of indurated clay at about every 4 feet, so hard as to require punching from 2 to 10 inches.
Black grit . .	10	
Blue clay . .	108	very hard.
	268	feet. Boring discontinued—no more water than at first. These two borings cost £145, and were 3 months in hand.

NORWOOD, NEAR STANDWELL.

A well 4 feet diameter sunk and bricked 280 feet through blue clay, into sand; the instant the sand was reached, the water rushed up to the top so fast as to endanger the workmen; it now stands within 8 feet of the surface of the canal, which is 86 feet above Trinity high water-mark.

BORING AT BRENTFORD, SIX MILES FROM LONDON.

Brick earth . .	9 feet.	
Sandy gravel . .	7	
Loam . . .	5	varies from 1 to 9 feet.
Sand and gravel .	4	varies from 2 to 8. Contains water.
Blue clay . .	200	
	225	feet. Boring discontinued—still in clay.

WOOLWICH SANDPITS.

Alluvium of various depths.

Rolled flints with sand	12 feet.	
Clay, striped brown and red, a few shells	6	water, merely drops.
Blue and brown clay, many shells	9	
Iron shot sand, with ocherous lumps	9	
Greenish sand, *clean*	8	
Greenish sand with flint pebbles	1	
Light ash-coloured sand, perfectly clean	35	
Green sand, with green chalk	1	
Chalk	unknown.	

PLUMSTEAD COMMON.

Shafts for Chalk.

No. I. Alluvial gravel, and pure ash-coloured sand	120 feet.
Chalk penetrated to	24
No water at	144
No. II. Alluvial Gravel	36

Stopped by the water.

No. III. At a small distance from this, stopped again by water at the same depth.

N.B. These three shafts were in the same field.

BOSTON HEATH, NEAR WOOLWICH.

A well sunk for water.

Gravel	65 feet.
Sandy beds	65
Chalk	70
	200

The water stands only 5 feet deep in this well; a trifling supply of water was found in the gravel.

LEWISHAM LOAM PIT HILL.

Alluvium various.

Striped sand, yellow, fine, and iron shot	10 feet.
Striped loam, and plastic clay, with thin seams of coaly matter	10
Yellow sand	3
Lead-coloured clay, with casts of leaves	2
Brownish clay with cytherea	6
Three thin beds of clay, the upper and lower with cytherea, and the middle with oysters	3
Loam and sand	4
Iron shot sand, with flint pebbles	12
Coarse green sand	5
Clean ash coloured sand	35
Green sand	1
	91

Chalk with nodules of flint unknown.

REDRIFF DRIFT SHAFT.

	Ft.	In.
Vegetable mould	6	9
Brown clay	0	9
Gravel with water	26	8
Blue clay	3	0
Loam	5	1
Blue clay, with bivalve shells	3	9
Gravel and calcareous rock	7	6
Light blue soil with pyrites	4	6
Green sand	1	9
Leafy clay	8	4
	68	1

A pipe sunk by Mr. Turner 95 feet deep, near Bermondsey new church:—when they reached 80 feet, the rod sunk down 15 feet at once; after pumping out several tons of green mud, the water rose to within 25 feet of the top; it rises and falls about three feet with the tide; the water is quite clear and tasteless. At a place not 500 yards from this, they sunk a pipe 190 feet with very little success, the water being out of reach of a pump, and appearing bad.

XVII.—*Some Accounts of Borings for Water in London and its vicinity.* *By Mr.* John Donkin, *M.Inst.C.E.*

PARTICULARS OF A WELL SUNK AT THE EXCISE OFFICE, IN BROAD STREET, LONDON.

In the first place, after excavating the upper stratum of gravel and loose soil, four cast-iron curbs were sunk, each 6 feet long; the lowest of these entered the clay about 3 feet; the digging was then continued through the clay to the depth of 140 feet, and a curb of brickwork within the iron curb was sunk the whole depth in the ordinary way, the iron curb serving merely to support the upper stratum, and to prevent the land water getting into the well. Boring was then resorted to, to the depth of about 20 feet, when the water appeared, and rose to within 60 feet of the top of the well; a copper pipe was then driven through the last-mentioned 20 feet, to keep the passage open for the supply.

WELLS SUNK AT MESSRS. BRANDRAM'S VITRIOL AND WHITE LEAD WORKS, LOWER ROAD, DEPTFORD.

The wood and brick curbing was sunk barely 30 feet; the bricks were laid in Roman cement to keep out the water from the land springs; the well was then bored to the depth of about 180 feet into a bed of chalk, from which the soft water rises and flows to within 9 feet of the top of the well, through wrought iron tubes riveted together. The strata are chiefly composed of yellow and green sand and gravel, like those found at the tunnel under the Thames.

ACCOUNT OF BORINGS MADE NEAR LONDON, WHERE THE WATER RISES ABOVE THE SURFACE OF THE LAND.

In Mr. Wilmot's garden at Isleworth, a boring was executed to the depth of 327 feet. The blue clay was found to exist from about 24 feet below the

ground level, with little variation of colour, to the depth of 240 feet: it is then of a lightish red, and afterwards of a darker colour very much variegated. At the depth of 308 feet it is blackish, and at 310 feet very black; at 311 feet it becomes yellow for some depth; then light green, followed by dark green, out of which the water rises, being a stratum of about 10 feet thick.

All the specimens, with the exception of the yellow, appeared to be clay; the yellow had a sandy appearance. The cast-iron pipe is sunk 327 feet, and is $2\frac{1}{4}$ inches diameter. The water rises about 10 feet above the ground, and the well supplies eight gallons per minute. The land-water here stands about 16 feet below the ground.

Lord Cassilis* has also had a boring executed in his grounds at Isleworth, to the depth of 290 feet: the quantity it supplies is about 30 gallons per minute, and its water rises about 30 feet above the level of the surface.

* Now Marquess of Ailsa.

XVIII.—*Description of the Method of roofing in use in the Southern Concan, in the East Indies, by Lieutenant* Fras. Outram, *Bombay Engineers. Communicated in a Letter to the late President,* T. Telford, *Esq., by Major-Gen. Sir* John Malcolm, *G.C.B., &c., Governor of Bombay.*

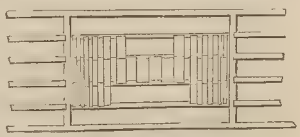
EXTRACT OF A LETTER FROM MR. TELFORD, ENCLOSING MR. OUTRAM'S PAPER.

" I beg to present to the Institution, a paper describing a mode of constructing " stone-roofed buildings in the East Indies, which, although it may be little applicable " in this climate, yet seems of considerable value as relating to an important part of " the British empire. It has been transmitted to me by direction of the Governor of " Bombay; as will be seen by the accompanying note of his private secretary.

" ' I have much pleasure in sending you, by desire of the Governor, the accompany- " ' ing copy of a letter from Lieutenant Outram, of the Engineers, on the subject of stone- " ' roofed buildings. The few houses which have been already constructed on this plan, " ' have been found to answer so well, that I understand Government have resolved to " ' construct, upon this principle, all the public buildings, wherever suitable materials " ' are to be procured.' "

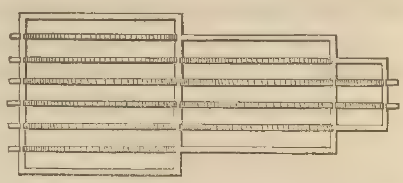
Nature of the arches composing the roof.

The roofing with stone (iron clay or laterite) in the Southern Concan is of a compound nature, consisting of two kinds of arches, the first being parallel to each other, from 2 to 3 feet apart, and very light; their average section being from 12 by 10 inches to 15 by 12; i. e. for roofs of from 25 to 35 feet span: so that when any two of these arches or ribs are complete, they are strong enough to bear slabs of stone 5 or 6 inches thick, extending a few inches over each, beginning from the wall and meeting at the top, thus forming a second complete arch, and making, with the ribs, a compound much stronger than vaulting of equal solidity over the same extent, made in the usual way.



Their lateral thrust.

The arches of one room are counteracted by those of the rooms on its sides, and so on for any extent; those of the end rooms being counteracted on their outer sides by buttresses or by the walls of baths, &c., so that the walls are required to be only sufficiently strong to support the mere weight of the masonry of the roofs, which has an average thickness of about 9 inches, excepting the plaster or tiles, and therefore in rooms of 400 square feet would be about one fifth the weight of the upper walls of a two-storied house. As the roof itself is of considerable altitude, the walls supporting it need not be of more than two-thirds the usual height.



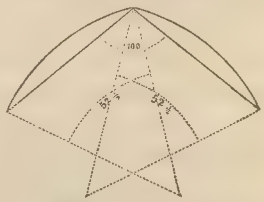
Walls.

Comparative weight of the whole roof.

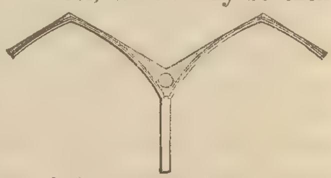
Loading of the arches.

One advantage of the lightness of these roofs is, that of whatever form the arches may be, very little *loading* will suffice; of course some arches would require no loading, but such are not the most convenient for roofs in general. The best appears to be a compound of two segments of a circle of 50 or 55°, their chords intersecting at an angle of about 100; such compound arch requiring a little loading at the top and the haunches, which, when duly added, gives an outer surface of two inclined planes to each roof, which may be then either plastered or tiled. But instead of loading the haunches throughout with solid rubble, it is better to do so partly with hollow masonry, to the upper surface of which may be given any slopes, which, by the connection of the opposite slopes of any two adjacent roofs, form a gutter of the securest kind. The average height of this gutter should be about one-third that of the roof, if to be plastered, but not so much if the roof is to be tiled.

Their form.



And outer surface.



Comparison between the expense of houses with stone roofs, and those tiled.

The expense of these roofs, including the outer plaster, has been found by myself and successor, in the Concan, to be much less than that of tiled roofs over the same extent. The walls should cost no more than those of a substantial bungalow, for although the transverse walls have a greater weight to support, yet as they need be only two-thirds the height, their total expense should not be greater than that of the walls of a substantial house. The only part of which the comparative expense remains to be considered, is the ceiling. The inner surface of the stone roofs, when finely plastered, forms an excellent ceiling, being light and cleanly, and most durable. The expense of this plastering, if not much ornamented, is below one-third that of the lath and plaster generally used.

Hence it is plain, and has been practically found, that the total expense of stone-roofed houses in the Concan, if properly constructed, is less than that of tiled houses of the same size; but the sums saved in annual and special repairs are of far greater consideration.

In the Deccan.

In the Deccan, where timber is so expensive, the comparative cost of these buildings would be still less, in all those parts of it where proper stone is met with.

The principal cause of the cheapness of these stone roofs, is the very little centering, &c., requisite. For as the ribs, or primary arches, are very light, centering of the simplest kind does for any one of them, and thus for all successively in either room. But as the centering cannot be removed from any rib till its counteracting ribs are complete, there is of course required one centering for each room, which, when one series of the primary arches is complete, may be removed with ease for the next, till a convenient number are ready for the superior arching, which of course is very quickly formed (as before described) without any centering.

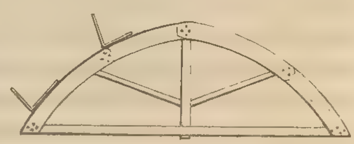
Stones fittest for these roofs.

The materials fittest for this kind of building are the various kinds of sand-stone, including the calcareous sand-stone of cutch. The laterite, or iron clay, although a good material, and the only one hitherto used, is apparently not so proper as the substance generally called free-stone, which, if worked with saws, &c., would be found to answer better than the laterite, which can be shaped only with a pick-axe, and is very heavy. This iron clay is found to extend from Bancoote E.N.E. to, I believe, Ceylon, lying over the trap-rock, even on the highest Ghauts, but is very unequal in thickness and quality; that of Purnalla and Pawnghur, for instance, being of the softest and

most porous kind, and that near Mahabulesher of the best. This stone, when exposed to rain, &c., becomes very hard if good, but if taken from any depth, is so soft as to be easily cut with a knife. It is hence called *soap-stone* at Belgaum and other Madras stations.

Method of working the ribs.

In making the primary arches, each workman should be provided with a small square, one leg of which being laid on the centering, the other will, of course, be the prolongation of a radius of the arch's curve. In beginning the arch, therefore, the workman has only to cut (with a small pick-axe for laterite, and a chisel for sand-stone) the upper end of the first stone, till it is adapted to the square, after which another stone is hoisted up, (the pulley being sufficiently high to allow it to swing freely over the centering,) and its lower end easily fitted to the surface just prepared; the upper end of it is then cut to the square for the reception of a third, and proceeding thus, both sides of the arch are formed till they meet in a key-stone at the top, which should be connected, *pro tempore*, by a slab, with the side wall, or with the next rib, for otherwise, these primary arches or ribs might be shaken down during the formation of the superior arches.



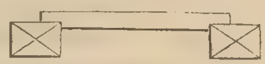
Securing them for the superior archway.

Advantages of the above method of working arches.

By the use of the square, the joinings of the arch-stones must all properly concentrate, although made by the most stupid workmen, and the arches are rendered perfect in much less time than they could have been by cutting the stones to chalked lines on the ground, as is usually done; besides, the stones may be of various lengths, and are thus worked with more freedom, and none spoiled.

Superior arches.

The stones of each superior arch should be cut at their ends, so that their inner surface be an inch or two below the upper surface of the ribs.



Plaster for the outer surface.

The cuttings of the laterite, good chunam, and sand, (sea sand should never be used,) in equal parts, form an excellent plaster for the outside of these roofs. The cuttings, or stone rubbish, will do pretty well without sand, but it should not be very finely powdered.

Precautions necessary in finishing a plastered roof.

The roof having been well washed, and not allowed to dry, the plaster should be laid on it throughout at once, and about

$2\frac{1}{2}$ inches thick. No fine chunam should be put over this plaster, but it must be constantly beaten with small pieces of wood, for two or three days. As the tempering of the plaster is of great consequence, every seven or eight square feet should be under a boy, who has, besides the piece of wood, a pot of water, to keep the chunam moist the whole time; at the end of the two or three days the plaster will have become very hard, and less capable of absorbing water; but after the boys have left it, there should be a sprinkling of water over the whole, as long as possible, for the longer these roofs are kept damp the stronger they become. Their surface should not be left very smooth; but if any cracks appear, they shew that the chunam has not been properly beaten, and should be filled by rubbing fine chunam into them.

In places subject to heavy rains.

As new chunam, however properly made, absorbs water, it will be advisable in the first season to guard against very heavy rain, by covering the surface with a thin coating of wax and oil, which is easily done by rubbing the mixture on the roof in the heat of the day.

Tiles may be used

But if chunam be scarce, or if it be not very good, the roof should be covered with tiles, (which would cost less than the plaster,) as may be seen by the small proportion the tiles bear in the expense of a tiled roof;—the form of the roofs render such an addition very easy.

If adopted in Europe, buildings of this kind would be as remarkable for warmth as in this country for coolness. But the plastering outside would not be advisable on account of the frost; tiles, however, or slate, would protect the roof completely.

Advantages of stone roofs, &c., in India.

The principal advantages of these buildings in this country are, their coolness, and the little expense incurred in annual and special repairs; indeed, the latter will never be required if the buildings be properly constructed at first. It is also very evident that they can never take fire, nor can white ants affect them; of course they could be built of several stories, the form of the floor ribs being merely a small segment of a circle, (or ellipse,) instead of a compound of two as in the roof. The upper floor of the jailor's house at Rutnaghery is thus built, as also part of another house.

All the buildings hitherto constructed on this principle are, in a climate perhaps the most unfavourable in India; for there is not a terraced roof, constructed in the usual mode over wood, that is proof against the excessive rains of the southern Concan.

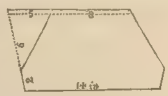
In some parts of it a mixture of stone and brick advisable.

This system could not be so economically adopted where trap or whinstone only is procurable, unless wood be very expensive, as at Poona; where a compound structure of roofs, between stone and brick, might be found even less expensive than common tiled roofs.

I take the liberty to add some remarks on brick and compound roofs of a similar construction, and a proposal for the use of domes in some cases, which I presume would be found more beneficial, and less expensive to government, than certain tile-roofed buildings.

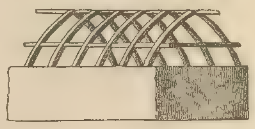
Stone ribs.

In the compound roofs, the primary arches, or ribs, to be constructed nearly as before mentioned, but being of harder stone, not so massive; the breadth of their section to be greater in proportion to the height. For arches of thirty feet span, the section of the rib stones may be as in the annexed sketch: their length being from two to four feet. The slopes at the upper corners are made for bricks.



Connecting slabs.

The ribs thus formed to be connected together by slabs of the same stone. One slab between every two at their tops, and another at each side, about the middle of the segment; the distance between the ribs to be about three feet.



Centering for the brickwork.

When thus formed, a piece of planked centering may be placed between any two ribs from the wall to the first connecting stone, so that a thin brick vault may be completed over that space,—the sides of both having been prepared (as before stated) to receive it. One piece of centering, in length only one fourth that of the ribs, and two or three feet wide, (consequently extremely light,) would suffice for the whole of the superior arching of a room, for the connected strength of the ribs (by the lateral stones) would be quite enough to sustain the then intermediate arches of brick; similar parts being done in succession, until the whole be covered. But care must be taken that a proper resistance be secured against the lateral thrust of the brick-work, which, however, is so very light, that an ordinary thickness for the side walls will do, if the two side ribs of each room be placed about one foot and a half, or two feet from them, so that, as with the laterite, flag stones might lie on the intermediate space; by the loading of which, a much greater resistance than requisite might be obtained.

Resistance against the lateral thrust.

Roofs of brick throughout.

If roofs are made of brick throughout, the proportion of the ribs and the vaulting should be somewhat different; for 25 feet

span, the ribs should have a section of 18 by 8 inches, and their intermediate space be about 2 feet wide, so that the ribs will nearly of themselves sustain the vaulting.

Conoidal domes. In many cases, however, surmounted domes formed on a compound conoid, two-thirds sphere, and the upper third cone, would be the most economical kind of roofing, particularly for detached buildings in this country, where verandahs or screens are necessary to protect them from sun and rain, which object would be at once gained by arches over the buttresses, the loading of which with mud rubble would of course increase their resistance, and likewise present an additional obstacle to the heat.

These domes would be found particularly advantageous in government buildings; for instance, those in the military department, in comparison with the barracks, store-rooms, hospitals, &c., now in use; they are far more easily ventilated by holes or windows, unlimited, at the sides, and one at the top of the roof, (the clumsy method adopted at present in barracks shews the necessity of ventilation,) and the great space inclosed by the roof alone ensures a plentiful supply of fresh and cool air in the closest days.—Secondly, their interior cannot be affected in the slightest degree, by the heat on the roof.—Thirdly, they include a larger space in proportion to their interior surface, thereby requiring less superficial repair, and being more easily kept clean.—Fourthly, they are altogether free from special repairs, and cannot take fire, nor be affected by white ants, which have hitherto not only destroyed buildings, but also the men's kits and public stores, the risk of which is perhaps of greater consideration, than the sums expended annually in repairing the buildings now in use; but those sums also would be saved in these brick-roofed buildings, except indeed whitewashing and repairing the floor, for the tiles of the roofing being fixed with chunam, would require no turning. They should be placed in horizontal divisions, by which means all angles will be avoided, and, unless the tiles actually break, there will be no repairs whatever requisite to the roof.

If the expense of annual and special repairs to buildings in general be considered, together with the destruction of stores by white ants, the loss by fire, and the loss of health, occasioned by the extremes of heat and cold under tiled roofing, it may perhaps be allowed that were roofs of masonry generally adopt-
Comparative expense. ed by Government, even at five times the original cost of the buildings hitherto used, there would accrue a saving of money; but it has been already proved, that the compound arched roofs are cheaper, and it may

now be shown, that those with the modified domes are also very economical; for, beginning with the walls, a circle being the least possible perimeter of a given area, the walls, if made of the usual height and thickness, would be much less expensive than those of an equal quadrangular space; a square for instance, would cost one-third more, and the shape generally given to hospitals and barracks, having the breadth one-fourth the length, merely because the roof would be very expensive if wider, would cost just twice as much. But as resistance is required against the lateral thrust of the dome, the additional buttresses necessary, would nearly double the expense of circular walls in all rooms above 20 or 25 feet diameter, were it not that the great height of the interior of the dome itself, renders it unnecessary to make the walls more than 7 or 8 feet high, i. e. just enough for the doors, &c. It will hence be perceived that the expense of quadrangular walls is greater than that of circular walls of only half their height with buttresses; and it will be seen by every one who understands the nature of a dome, that a surmounted dome, as described, would be perhaps the cheapest mode possible (unless brick and chunam are enormously expensive) of substantially covering a given space, and the larger that space the greater the advantage of this dome over wood roofs, &c.: for such requires no centering whatever, although 300 feet diameter; and is built under the superintendence of one intelligent person, as easily as the upper walls of a house, because the arches over the buttresses afford a landing-place for the materials, and the outer surface of the dome gives a footing to the workmen without any scaffolding; the expense, therefore, should be estimated as for upper walls, i. e. the same rate for the solid masonry of the dome, which, together with the tiles covering it, will cost less than a common tiled roof, over an equal extent.

Disadvantages. The disadvantages of domes, are, their inconvenient shape for houses in general, and upper storied houses in particular, their inelegant appearance, unless the walls be of a proportionate height, which would increase the expense enormously in the buttresses, their depths being in direct ratio with the heights of the walls, so that if the height of the walls be doubled, the expense of the buttresses is fourfold. But where no stone is procurable, a house formed of several dome-roofed rooms, properly connected together, would be found not more expensive than one of the same size with compound arches, i. e. in one-storied houses only, both being made of brick. Of course spheroidal roofs may be made nearly as easily as domes, but they would cost more, and would not do so well for tiles.

XIX.—*Experiments of the Resistance of Barges moving on Canals, by* Henry R. Palmer, *Esq., V.P.Inst.C.E. Addressed to the late President,* Thomas Telford, *Esq.*

The statements that have been laid before the public in reference to the swift passage of boats along the Ardrossan Canal, having occasioned a renewal of, and more extended enquiry into the subject of the resistance to which the motion of boats and barges is exposed, I think it important that every useful fact relating to it should be collected and placed in the records of the Institution of Civil Engineers.

With this view I have transcribed the particulars of some experiments with which, through your kindness, I had the honour to be entrusted in the year 1824, when the comparison of the cost of conveyance by canals and railways constituted a popular question.

In the performance of the experiments referred to, I very soon perceived the difficulty of obtaining the results with that accuracy which was required.

The moving forces being animal power, one imperfection arose from the difficulty of preserving an equable motion. From the same cause I was unable to obtain, at will, any given velocity, so that the results might be obtained in the order required for a tabular registration. A third imperfection was occasioned by wind, which, however slight to the sensation, materially affected the results.

Considering, however, that the experiments were upon the large scale, that the circumstances affecting each are recorded, and that no assumptions were allowed to interfere, they are susceptible of some useful deductions, more especially when received, in comparative order, with facts which have been since and which may hereafter be obtained.

The purport of the experiments was entirely of a practical nature, and therefore they were tried by means strictly conformable with those actually in common use. The towing ropes were attached to the barges at the same parts as usual, the lengths of the ropes used were of the customary dimensions on each canal respectively, and the moving power exerted in the same position, viz., along the towing path on one side of the canal.

The results, therefore, do not exhibit precisely the resistances of the barges in a straight line, uninfluenced by the rudder, but that resistance which the circumstances oblige the horse to overcome, which from the obliquity of the line of force with that of the motion of the barge, gives an increased quantity in proportion. Although this error is of small magnitude, and will have little effect in the proportion of the results to each other, (which is an important feature in the experiments,) it may lead to incongruities in the comparison of these experiments with others determined by other means, if not attended to.

Method used for ascertaining the Resistances of the Barges moving on Canals.

A sheeve or pulley was suspended from the post to which the towing line is usually fastened, the towing line was then passed over that pulley, and the end of it fastened to the weights that were to indicate the resistance; the barge was then towed in the usual manner, and the weight being always insufficient at the commencement, it was raised up to the pulley, and was suffered to remain so, until the barge appeared to be in a regular and uniform motion. Additional weights were then suspended, until they fell to about 12 inches from the pulley, when they were so adjusted as to remain suspended there, their only motion being a slight vertical vibration, occasioned by the stepping of the men employed to draw the line.

A straight part of the canal was chosen, and the length through which an experiment was continued was divided into equal parts, each being marked by a stake. The equality of the motion was therefore ascertained by the time occupied in passing each division, so that when the divisions of the whole space had been passed in equal times, and the weights had during the whole time remained within the same limits of vibration, the experiment was considered as having been fairly made.

The experiments being made on different canals, it was always found necessary to practise the men in drawing the barges, before they were found to walk with sufficient regularity, and the loss of time thus engaged caused frequent regret that soldiers could not be obtained for the purpose.

One of the experiments (No. 17) given in the Table was furnished to me by Mr. Bevan, the engineer to the Grand Junction Canal Company. In the four last I was favoured with the assistance of Professor Barlow, the late Mr. Chapman of Newcastle, Mr. B. Donkin, and Mr. Bevan.

No. of Experiment.	Name of the Navigation.	Description of the Vessel.	Place of the Experiment.	Dimension of the Navigation.	Dimension of the Vessel.	Draught of Vessel.	Space of the Experiment.	Time of the Experiment.	Velocity in Miles.	Resistance, or moving Force.	Load, or useful effect.	Whole effect.	Fraction of the Force to the Load.	Ditto, including the Barge.	Number of the Horses, Men, &c.	Observations.
				Feet.	Ft. Inches.	Ft. Inches.	Chains.	Minutes	Miles.	lbs.	Tons.	Tons.				
1.	Mersey and Irwell.	Packet.	Near Runcorn.	48 wide 6 deep	62 9 long 13 9 wide	1 8 front 2 stern	79	12	4.9300	343	1.20	43½	$\frac{1}{73}$	..	3	Vessels with masts and rigging.
2.	Do.	Kent flat.	From Barton to Meadwheel Lock.	River	64 10 14 6	4 1	165	48	2.5757	242	40	92	$\frac{1}{370}$	$\frac{1}{851}$	2	Surface exposed to wind much greater than that of ordinary canal barges.
3.	Do.	Haywodd flat.	Old Quay to Meadwheel Lock.	Do.	Do.	2 0	265	56	3.5378	140	empty	52	..	$\frac{1}{832}$	2	Canal irregular in depth.
4.	Do.	Do.	Meadwheel to Barton Lock.	Do.	Do.	2 0	165	33	3.7575	140	do.	52	..	$\frac{1}{832}$	2	Wind at the time sensibly affected the experiments. Nos. 3 and 4 disturbed the water considerably.
5.	Ellesmere.	Small boat.	Near Ellesmere.	30 wide 6 deep	69 long 3 6 wide	2 5	36.8	6	4.6000	168	10	14½	$\frac{1}{133}$	$\frac{1}{193}$	Men.	The only errors observable in the experiments on the Ellesmere Canal were attributable entirely to the wind, the effect of which is seen in the results.
6.	Do.	Do.	Do.	Do.	Do.	Do.	30.27	4⅚	4.6900	170	10	14½	$\frac{1}{132}$	$\frac{1}{191}$	Do.	
7.	Do.	Do.	Do.	Do.	Do.	Do.	30.27	6′ 15″	3.6300	77	10½	15	$\frac{1}{305}$	$\frac{1}{436}$	Do.	
8.	Do.	Do.	Do.	Do.	Do.	Do.	39.27	7′ 40″	2.9600	50	10½	15	$\frac{1}{470}$	$\frac{1}{672}$	Do.	
9.	Do.	Common barge.	Do.	Do.	68 6 long 7 0 wide	1 8 front 2 7 stern	30.27	15′ 30″	1.9000	50	21	30	$\frac{1}{940}$	$\frac{1}{1344}$	Do.	
10.	Do.	Do.	Do.	Do.	Do.	Do.	39.27	10′	2.9450	66	10¾	19¾	$\frac{1}{365}$	$\frac{1}{670}$	Do.	With the wind.
11.	Do.	Do.	Do.	Do.	Do.	Do.	39.27	10′ 30″	2.8050	91	10¾	19¾	$\frac{1}{264}$	$\frac{1}{485}$	Do.	Against the wind.
12.	Do.	Do.	Do.	Do.	Do.	Do.	39.27	10¾	2.7300	98	20¾	29¾	$\frac{1}{470}$	$\frac{1}{680}$	Do.	
13.	Do.	Do.	Do.	Do.	Do.	Do.	39.27	9	3.2700	175	20¾	29¾	$\frac{1}{266}$	$\frac{1}{381}$	Do.	
14.	Do.	Two barges.	Do.	Do.	Do.	Do.	39.27	10½	2.8050	164	21	39	$\frac{1}{237}$	$\frac{1}{532}$	Do.	
15.	Do.	Do.	Do.	Do.	Do.	Do.	18.63	5′ 25″	2.5800	172	21	39	$\frac{1}{273}$	$\frac{1}{507}$	Do.	
16.	Do.	Do.	Do.	Do.	Do.	Do.	30.30	9′ 5″	2.5000	196	42	60	$\frac{1}{480}$	$\frac{1}{685}$	Do.	
17.	Grand Junction.	Common boat.	..	..	..	..	10 miles	4′ 5′	2.45	80	..	31	..	$\frac{1}{868}$	Horses.	This experiment made by Mr. Bevan.
18.	Do.	Do.	Paddington.	45 wide 5 deep	69 feet	..	10 chains	2′ 7″	3.64	80	empty	6½	..	$\frac{1}{182}$	Men.	Corrected for the effect of the wind, estimated at 8 lbs. The weight in both cases was 72 lbs., and the experiment was repeated with the barge turned about, merely for this comparison.
19.	Do.	Do.	Do.	Do.	Do.	Do.	10 ,,	4′ 35″	3.27	64	do.	do.	..	$\frac{1}{328}$	Do.	
20.	Do.	Do.	Do.	Do.	Do.	Do.	10 ,,	3′ 52″	3.87	308	21½	27	..	$\frac{1}{203}$	Men & horses.	There was no wind when the last two experiments were made.
21.	Do.	Do.	Do.	Do.	Do.	Do.	10 ,,	6′ 8″	2.44	77	21½	27	..	$\frac{1}{811}$	Men.	

The following are the particulars of the last four experiments, made on the Grand Junction Canal, at Paddington, by Messrs. Barlow, Chapman, Donkin. and Palmer.

Experiment I.—Empty barge; weight, $6\frac{1}{2}$ tons; force employed, 72 lbs.; fraction of the force to the whole effect, $\frac{1}{205}$; wind in favour.

Number of Stakes.	Time.	Time between the Stakes.	Velocity per hour, in miles.
	′ ″	″	
1	0 29	29	3.104
2	1 7	28	3.214
3	1 34	27	3.333
4	2 0	26	3.461
5	2 24	24	3.750
6	2 49	25	3.600
7	3 13	24	3.750
8	3 39	26	3.461
9	4 3	24	3.750
10	4 28	25	3.660
11	4 54	25	3.600
12	5 15	22	4.090
13	5 41	26	3.461

Experiment II.—Empty barge; weight, $6\frac{1}{2}$ tons; force employed, 72 lbs.; fraction of the force to the whole effect, $\frac{1}{205}$; against wind.

Number of Stakes.	Time.	Time between the Stakes.	Velocity per hour, in miles.
	′ ″	″	
12	0 33	33	2.727
11	1 2	29	3.104
10	1 29	27	3.333
9	1 56	27	3.333
8	2 24	28	3.214
7	2 51	27	3.333
6	3 18	27	3.333
5	3 45	27	3.333
4	4 11	26	3.461
3	4 40	29	3.104
2	5 8	28	3.214
1	5 37	29	3.104

EXPERIMENT III.—Load, $21\frac{1}{2}$ tons, which, added to $6\frac{1}{2}$ tons, the weight of the barge, gives 28 tons, the whole effect; fraction of force to whole effect, $\frac{1}{203}$; force, 308 lbs.

Number of Stakes.	Time.	Time between the Stakes.	Velocity per hour, in miles.
1	′ ″ 38	″ 38	2.395
2	1 3	25	3.600
3	1 $26\frac{1}{2}$	$23\frac{1}{2}$	3.829
4	1 $49\frac{1}{2}$	23	3.918
5	2 12	$22\frac{1}{2}$	4.000
6	2 $34\frac{1}{2}$	$22\frac{1}{2}$	4.000
7	2 $57\frac{1}{2}$	$23\frac{1}{2}$	3.829
8	3 21	$23\frac{1}{2}$	3.829
9	3 $44\frac{1}{2}$	$23\frac{1}{2}$	3.829
10	4 9	$24\frac{1}{2}$	3.673
11	4 32	23	3.918
12	4 56	24	3.750
13	5 19	23	3.918

EXPERIMENT IV.—Load, $2\frac{1}{2}$ tons + $6\frac{1}{2}$ tons = 28 tons, the whole effect; force employed, 77 lbs.; fraction of force to whole effect, $\frac{1}{814}$.

Number of Stakes.	Time.	Time between the Stakes.	Velocity per hour, in miles.
1	′ ″ 1 6	′ ″ 1 6	1.363
2	1 54	48	1.875
3	2 $34\frac{1}{2}$	40	2.222
4	3 13	$38\frac{1}{2}$	2.337
5	3 49	36	2.500
6	4 25	36	2.500
7	5 1	36	2.500
8	5 $37\frac{1}{2}$	$36\frac{1}{2}$	2.465
9	6 15	$37\frac{1}{2}$	2.400
10	6 $42\frac{1}{2}$	$37\frac{1}{2}$	2.400
11	7 30	$37\frac{1}{2}$	2.400
12	8 6	36	2.500
13	8 42	36	2.500

TABLE OF THE DIMENSIONS OF THE BARGES USED ON THE GRAND JUNCTION CANAL.

Distance from the head of the barge.	Greatest width at the several distances.		Width inside at the several distances.		Depth below water, on the one side.	Depth below water, on the other.	Depth above water, on the one side.	Depth above water, on the other.	Girth at the several distances.	
Feet.	Feet.	In.	Feet.	In.	Inches.	Inches.	Inches.	Inches.	Feet.	In.
5	5	$3\frac{1}{2}$	1	10	...	...	35.3	36.0	10	$3\frac{1}{2}$
10	6	6	4	2	9.2	8.5	32.9	33.1	11	$10\frac{1}{2}$
15	6	$8\frac{1}{2}$	5	7	...	...	31.5	32.2	13	0
20	6	$7\frac{3}{4}$	5	11	9.6	8.4	31.5	32.3	13	$1\frac{1}{2}$
25	6	8	6	0	...	...	31.4	31.9	13	2
30	6	9	6	0	...	...	31.1	31.4	13	2
35	6	$8\frac{1}{4}$	6	0	...	...	31.0	31.4	13	2
40	6	8	6	0	9.8	8.9	31.1	31.7	13	2
45	6	$7\frac{1}{2}$	6	0	.1	...	31.0	31.8	13	$2\frac{1}{2}$
50	6	8	5	11	11.1	9.3	30.9	31.4	13	$2\frac{1}{4}$
55	6	9	5	1	...	...	31.4	31.8	12	9
60	...		4	2	9.7	9.0	32.9	33.1	11	3
65	...		1	10	...	..	36.8	37.3	9	7
69 feet the whole length, not including the rudder.										

The weights with which the barges were loaded were those used for determining the gauge marks on the part of the Company.

The experiments on the Mersey and Irwell canal were made upon vessels that happened to arrive at the time, without preference. The first was upon the packet which is used to convey passengers between Manchester and Runcorn, and is usually towed at the rate of $5\frac{1}{4}$ miles per hour.

Nos. 5, 6, 7, and 8 were made on the Ellesmere canal, with a boat built for the purpose, and which was of the same length as those commonly used, but exactly half their width.

Nos. 9, 10, 11, 12, and 13, were made with one of the ordinary canal barges.

Nos. 14, 15, and 16, were made with two boats joined together end to end, and the curves, to the head of one and the stern of the other, so planked over as to form one boat of double the ordinary length.

No. 17, having been made by Mr. Bevan, I have no other information relating to it than the facts as given in the table.

Nos. 18, 19, 20, and 21, were tried under circumstances as favourable as are usually met with; the effect of the wind was, however, very apparent.

Every variation in the resistance through all the experiments was easily discernible when it amounted to six ounces, and sometimes less.

In conclusion, I think it necessary to remark, that in such experiments as these which have been described, the action of the wind, whether in favour or opposed to the motion of the vessel, should receive the nicest attention. The difficulty does not consist only in ascertaining the amount of the atmospheric action at any given time, but in making a due allowance for its variations during the time of one experiment: still weather should be chosen for the purpose, and the experiments should be made early in the morning, before any sensible wind has arisen.

The above experiments were submitted to Peter Barlow, Esq., F.R.S., and the following are the deductions he made from them.

Report of Peter Barlow, Esq., F.R.S., on the Experiments of Henry R. Palmer, on the resistance of Barges on Canals, &c.

In order to reduce the law of resistances from the foregoing experiments, it is requisite that the comparison should be made between those on the same boat and under the same circumstances; for the resistance opposed to different boats will depend on their transverse sections, their draught of water, the section of the canal, and various other circumstances, which will prevent the deduction of any general law applicable to all cases.

Mr. Palmer states that the first four experiments on the Ellesmere canal, with a small boat, were made under particularly favourable circumstances of weather, &c. These therefore may be employed for deducing the law of the resistances, as it depends on velocity.

It is generally assumed, on the common theory of fluids, that the resistance varies as the square of the velocity, but it has been found that this law does not obtain in practice, and different experimenters have obtained different results, varying from the 2d to the $\frac{5}{2}$ power of the velocity. It will appear, however, from the following investigations, that in the case of loaded canal boats, it varies in a still higher ratio, viz., as the cube of the velocity very nearly, if not exactly. In order to make this comparison, it is only necessary to proceed as below, by saying,

$$V^m : v^m :: F : f.$$

using for V, v, F, f, the actual velocity and moving powers employed.

From this proportion is very easily obtained the theorem $m = \frac{\log F - \log f}{\log V - \log v}$; and employing in this the velocities and forces given in the first four experiments, there is obtained the following results, comparing the experiment

1 to 3	$m = 3.2$
1 to 4	$m = 2.7$
2 to 3	$m = 3.0$
2 to 4	$m = 2.6$
Mean value of	$m = 2.9$, or 3 nearly.

By comparing experiments 7 and 8, which are made under like circumstances and on the same boat, we find $m = 3.2$, and in the same way experiments 17 and 18 give nearly the same result, viz., $m = 3.0$, the general mean being $m = 3.0$.

It is clear, therefore, that, whatever may be the deduction from theory, the actual resistance of canal boats varies very nearly as the cubes of the velocities; and, by adopting this law, the velocities due to any force and load may be computed from the velocity and resistance in any other case being given.

And as it will be seen by the experiments on the different railways, that at a mean, one lb. will draw along 180 lbs., and that a power of 1 to 200 is the greatest that the most perfect railway can ever be expected to attain; I have computed what velocity is attainable on a canal answering to those two cases, viz., when the moving force is $\frac{1}{180}$th part of the whole load moved. These results are given in the following table, omitting those made on empty boats and sea-going barges.

Navigation, description of the barges, &c.	Authority.	Whole load, including barge.	Moving force.	No. of lbs. drawn by 1 lb.	Rate, in miles per hour.	Computed rate when 1 lb. draws 180 lbs.	Computed rate when 1 lb. draws 200 lbs.	Remarks.
		Tons.	lbs.					
Ellesmere boats, half the usual breadth; length 69 feet; breadth 3 feet 6 inches.	Palmer.	$14\frac{1}{2}$	168	193	4.60	4.70	4.54	
		$14\frac{1}{2}$	170	191	4.69	4.78	4.62	
		15	77	436	3.63	4.97	4.70	
		15	50	672	2.96	4.59	4.43	
Common boat.	Do.	30	50	1344	1.90	3.71	3.58	
Common boat, half load.	Do.	$19\frac{3}{4}$	79	500	2.94	4.29	4.12	The moving weights were 66 lbs. and 91 lbs.; they are corrected for the effect of the wind.
		$19\frac{3}{4}$	78	567	2.80	4.10	3.96	
Common boat, full load.	Do.	$29\frac{3}{4}$	98	680	2.73	4.25	4.09	
		$29\frac{3}{4}$	175	381	3.27	4.19	4.05	
Two common boats, end to end.	Do.	39	164	532	2.80	4.01	3.87	
		39	172	507	2.58	3.64	3.51	
Do. full load.	Do.	60	196	689	2.50	3.91	3.75	
Common boat.	Bevan.	31	80	863	2.45	4.13	4.08	
Common boat, full load.	Barlow, Donkin, &c.	27	308	203	3.87	4.02	3.88	
		27	77	814	2.44	4.04	3.90	
					Mean	4.22	4.06	

It is clear, therefore, that on a canal, when the moving power is $\frac{1}{200}$th of the whole load, including the barge, it may be taken forward at the rate of 4 miles per hour, and that when the force is $\frac{1}{180}$th, the rate of transfer will be $4\frac{1}{4}$ miles per hour. It is easy also, from what has now been stated, to compute the power on a canal, at different velocities: for example,

At 4	miles per hour, 1 lb. will draw	200 lbs.
$3\frac{3}{4}$	....	243
$3\frac{1}{2}$	....	299
$3\frac{1}{4}$	....	373
3	....	474
$2\frac{3}{4}$	....	615
$2\frac{1}{2}$	....	819
$2\frac{1}{4}$	....	1124
2	....	1600

XX. *An Elementary Illustration of the Principles of Tension and of the Resistance of Bodies to being torn asunder in the Direction of their Length.* *By the late* T. TREDGOLD, *M.Inst.C.E.*

WRITERS on mechanics have usually stated that the resistance which a body offers to being torn asunder in the direction of its length is proportional to the area of its section, but without showing that there are certain conditions necessary to obtain results in this proportion. The object of this paper is to show in a plain and simple manner, the conditions necessary to render the resistance proportional to the area, and that there are few instances where the rule will be found true in practice.

If a weight be suspended by a small filament or thread of any species of matter, there can be no doubt that the strain at any point is equal to the weight suspended by the section at that point; and when the weight is sufficient to tear the filament as under such weight may be considered the measure of its cohesion.

Fig. 1. Thus the weight W may be considered the measure of the cohesion of a filament at C; neglecting the weight of the portion CB of the filament for the sake of simplifying the reasoning.

Let us now suppose that two threads of exactly equal strength are applied at a given distance apart, to support a weight.

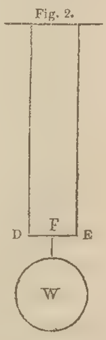


Fig. 2. Thus the weight W may be supported by two threads or filaments by means of a small bar DE.

The filaments in this case being supposed to be of equal strength, it is obvious that the stress on them ought to be equal, otherwise only that one which has the greatest stress on it will bear its proportion of the breaking weight.

And in order that the stress on both filaments may be equal, it is evident that the point F, from which the weight is suspended, should be exactly in the middle between the filaments. For if the point F be nearer to the filament E than to D, then E will be most strained, and consequently break before the other.

The proportion of the strain is easily found by the properties of the lever. Call the force necessary to pull one of the filaments asunder P, and we have,

$$DF : DE :: P : W; \text{ whence } \frac{DE \times P}{DF} = W.$$

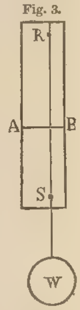
This is the greatest weight the two filaments will support, because when

the weight pulls one apart the other will break of course. But if both filaments were equally strained the equation would be $2\,P = W$, and this can happen only when $DE = 2\,DF$, or when F bisects E D.

If the point F be only one sixth out of the centre of the bar then $\frac{6 \times P}{4} = 1\frac{1}{2}\,P = W$. Hence, the filament AD will be exerting only half its power when BE breaks.

Even in this stage of the inquiry we can see how important it is that the links of chains should be formed so as to have the centre of tension in the centre between the sides of the link. But when we have to consider the extension of the material, as well as the difference of stress, the variation will be found more considerable.

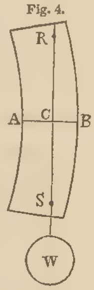
Fig. 3.



The extension of a substance is nearly, if not accurately, as the strain upon it.

Fig. 3. Let a body be suspended by a pin at R, and suspend a weight by another pin at S, so that a line drawn through the supporting points may not be in the middle of the width AB; but nearer to B than A.

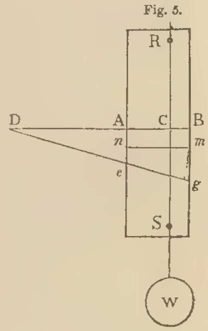
Fig. 4.



Here the solid parts below the line BA perform the same office as the lever or bar, in fig. 2, and the strain will be greater at B than at A, and the extension will also be greater, and in the same proportion as the strain; and in consequence of the lengthening of the side B, the bar will become curved.

Fig. 4. Represents the curved state of the bar. The curvature it acquires will be such that the resistance of the part AC is equal to the resistance of the part CB; and till this equilibrium of resistance takes place, the bar will continue to curve.

Fig. 5.



The distance of the neutral point may be found by different methods, but a diagram on the bar will best illustrate this point. Let Bm, and An, Fig. 5, be two equal portions of the surface of the bar in its natural state, and Bg, Ae, the length of the same portions where the bar is strained by the weight W. The lines drawn through AB, and eg, must meet in a point wherever the stress on the parts is not equal; and the point thus determined is called the neutral point.

To find the neutral point put DC, its distance from the direction of the straining force, equal z; and DB,

its distance from the extended surface of the bar equal a'; make $CB = y$, and $AC = x$.

Since the extension is proportional to the strain, we shall have,

$$a : \overline{z - x} : : f : \frac{f(z-x)}{a} =$$

the force of a filament at the distance x from C; its force at B being f. And suppose the section to be a rectangle of the breadth b; we have $\frac{f\,b\,(z-x)\,\dot{x}}{a} =$ the fluxion of the force of any filament $b\,\dot{x}$; and its effect is as the leverage x, therefore the fluent of $\frac{f\,b\,(z-x)\,x\,\dot{x}}{a}$ = the resistance of the part AC of the bar, or,

$$\frac{f\,b\,x^2(3\,z - 2\,x)}{6\,a} = \text{the resistance of AC.}$$

In like manner it will be found that the resistance of BC, is $\frac{f\,b\,y^2(3z + 2\,y)}{6\,a}$.

Now, in order that there may be an equilibrium of resistance, we must have

$$\frac{f\,b\,y^2(3\,z + 2\,y)}{6\,a} = \frac{f\,b\,x^2(3\,z - 2x)}{6\,a}.$$

or,

$$y^2(3\,z + 2\,y) = x^2\,(3\,z - 2\,x).$$

Whence we find the distance of the neutral axis,

$$z = \frac{2\,(x^3 + y^3)}{3\,(x^2 - y^2)}.$$

If d be the whole depth AB, then $x = d - y$ and

$$z = \frac{2\,(d^2 - 3\,d\,y + 3\,y^2)}{3\,(d - 2\,y)}.$$

Consequently $a = z + y = \frac{2\,d^2 - 3\,d\,y}{3\,(d\,-2\,y)}$ = the distance of the neutral axis from the point B.

The distance of the neutral point being found, the solution becomes easy. Thus, let f be the cohesive force of a square inch, d = the depth, b = the breadth, and a = the distance of the neutral axis from the extended side.

The force of a filament $b\,\dot{d}$ will be $f\,b\,\dot{d}$, at the extended side; and its force in any other part will be,

$$a : a - d\ : : f\,b\,\dot{d}\ : \frac{f\,b\,(a-d)\,\dot{d}}{a}.$$

The fluent of $\frac{f\,b\,(a-d)\,\dot{d},}{a}$ is, $\frac{f\,b\,d\,(2\,a-d)}{2\,a}=\text{W}=$ the weight the bar will support.

But we have found that $a=\frac{2\,d^2-3\,d\,y}{3(d\;-2\,y)}$; hence substituting this value of a, we have,

$$\frac{f\,b\,d^2}{4\,d-6\,y}=\text{W}.$$

That is, a bar strained in the direction of its length, the weight it will support is equal to the breadth multiplied by the square of the depth, and by the cohesion of a square inch in lbs.; divided by four times the depth added to six times the distance of the direction of the straining force from the nearest side of the bar; the quotient thus obtained expresses the weight it would support in lbs.; and the dimensions are all supposed to be taken in inches.

If the distance of the direction of the straining force be half the depth, then

$$y=\tfrac{1}{2}d \text{ and } \frac{f\,b\,d^2}{4\,d-6\,y}=f\,b\,d=\text{W}.$$

But if $y=\frac{1}{3}d$, then $\frac{f\,b\,d^2}{4\,d-6\,y}=\frac{f\,b\,d}{2}=\text{W}$; which shows that by this variation of the direction of the straining force, half the strength of the bar is lost.

In the same manner the investigation may be extended to other forms, but the subject having been already treated by a different process of reasoning, and also by a different notation, in the second edition of my book on the Strength of Iron, I will not proceed further with analysis, but confine myself to a few practical conclusions.

In making a joint to resist tension, the surface in contact should be so formed as to render it certain that the direction of the tensile force may be exactly, or at least very nearly, in the centre of the bars that have to resist it.

In all calculations of the magnitude of bars, &c., to resist tension, the greatest possible variation in the direction of the straining force should be calculated upon, and the dimensions determined accordingly.

If the connections of a bar, to resist tension, be made as in fig. 6, it is very difficult to get them fitted so perfectly as to cause the direction of the tensile force to be in the centre of the bar.

A connection by a piece in the middle, as fig. 7, is more certain to effect the object of limiting the variation of the direction of the straining force, as will be obvious from the figure, and the joint should be fitted so as to bear at A the centre of direction.

Fig. 7.

The like remarks apply to joints in long ties, joints of the forms shewn in figs. 8 and 9, are very common, and very good forms for a connecting joint.

I have, however, not unfrequently seen joints in ties formed as in figs. 10, 11, 12, where the line of strain is at or beyond the side of the bar, and such a tie would obviously bend till the strain on its parts would become very unequal.

Fig. 8, 9.

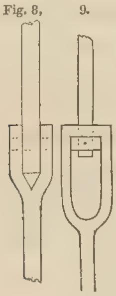
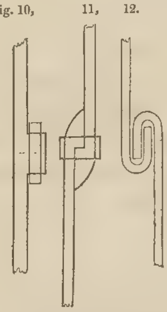


Fig. 10, 11, 12.



The same conclusions are obtained by considering the forces to be pressive, instead of tensile, with the exception that the strain increases the curvature when a curved bar is compressed, while it diminishes it when the bar is extended. Hence it is of still greater importance to attend to the variation from the centre of magnitude of the resisting body in cases where it is to sustain pressure.

This difficult subject, for so it has been considered by an eminent authority, whom I shall presently quote, is capable of an easy popular illustration with regard to pressure.

When a pressure is on the centre of the block which supports it, and the block is a material of equal texture, then all the parts must offer an equal resistance to the pressure, there being no reason why one part in the bounding surface of the block should take a greater or less strain, all being similarly affected.

But if the pressure be nearer to one side of the block than the other, the resistance becomes obviously unequal. If an elastic body be employed in the experiment, the inequality of compression is decidedly shown; but what body is there which has not some degree of elasticity? or what is worse, allows of compression without restoration of figure when the pressure is removed?

The consequence of a pressure being at a distance from the centre of the supporting surface does not simply depend on the distance, but also on the degree of compression it produces, for the form of the support, whether it be a column, a pillar, or a wall, will alter till there is an equal resistance on each side of the line of pressure, if it does not totally fail.

These considerations will explain many circumstances which occur in practice, where walls, piers, and arches undergo changes of form, which have always been familiar to practical men under the name of settlements.

The first person who remarked the deficiency of ordinary theories in regard to inequality of resistance was Dr. Robison, in his article on the strength of materials; he was more conversant with theory than practice, but his remarks have some interest. Speaking of Euler's theory of columns, he says, "It leads to "the greatest mistakes, and has rendered the whole false and useless. It would "be just if the column were of materials which are incompressible. But it is evi-"dent, from what has been said above, that by the compression of the parts, the "real fulcrum of the lever shifts away from the point C (fig. 5), so much the more "as the compression is greater. In the great compressions of loaded columns, and "the almost unmeasurable compressions of the truss beams in the centres of "bridges, and other cases of chief importance, the fulcrum is shifted far over to-"wards (D), so that very few fibres resist the fracture by their cohesion; and "these few have a very feeble energy or momentum, on account of the short arm "of the lever by which they act. This is a most important consideration in "carpentry, yet it makes no element of Euler's theory. It will now be asked "(he continues) what shall be substituted in place of this erroneous theory? what "is the true proportion of the strength of columns? We acknowledge our ina-"bility to give a satisfactory answer. Such can be obtained only by a previous "knowledge of the proportion between the extensions and compressions produced

" by equal forces, by the knowledge of the absolute compressions producible by " a given force, and by a knowledge of the degree of that derangement of parts " which is termed crippling. These circumstances are but imperfectly known to " us, and there lies before us a wide field of experimental inquiry."

Such was Dr. Robison's view of the subject, but the question did not long remain in that state. Our celebrated countryman, Dr. Thomas Young, soon discovered the proper mode of investigation, which was published in 1807, and yet, strange as it may seem, the popular writers on mechanics in this country, as well as on the continent, either have not seen, or do not comprehend, the brief but elegant demonstration Dr. Young has given. We can attribute it only to the difficulty of following the inquiries of that able philosopher without a most extensive knowledge of mathematics and of nature.

XXI. *Details of the Construction of a Stone Bridge erected over the Dora Riparia, near Turin, by Chevalier Mosca, Engineer and Architect to the King of Sardinia, &c., &c. Drawn up and communicated by Mr. B. Albano, A.Inst.C.E.*

This bridge, which may be characterized as the boldest work of the kind, is erected within the suburbs of Turin, over the Dora Riparia, a river ordinarily shallow, but liable to heavy floods, during which it becomes extremely rapid, owing to the great declivity of its bed.

It consists of a single large arch of granite, (of which the elevation is shewn in Plate XVII.,) resting on solid abutments of the same materials; its line of direction is in continuation of the axis of the main road which crosses the Alps from France, called the road of Italy, and it has an unvarying surface level throughout its whole length.

The foundations of the abutments are laid upon piles headed with cross sills, on which rest the first courses of stone with offsets: over these are placed five other horizontal courses, from the uppermost of which the arch springs, being a segment of a circle, having a span of 147.63836 feet, and a versed sine of 18.04468 feet. These proportions, which correspond to an arc of $54° 56' 45'' 26'''$, render it, I believe, the flattest arch of this form yet constructed in Europe.

The lightness of appearance derived from the flatness of the arch is much increased by the introduction of two *ugnature*, or cornes de vaches, (as the French call them,) which, rising from the third course above the springs of the principal arch, form a second one of a somewhat larger span, (as represented in the Plate,) tangential to the first at the intrados of the key-stone, and having a versed sine of 12.1391 feet.

The sides of the abutments are of a convex form, and thus acting towards their bases as cut-waters, give, in conjunction with the ugnature, a more free and open passage for the descent of the stream in time of floods, whilst their upper parts add elegance to the wings of the structure and increase the width of the approaches: these last are bounded on each side by an advanced body of wall adorned at the saliant angle by a pilaster, and terminating at the other end on the banks of the river, thus making the total length of the bridge between these extreme points 300 feet.

The arch is composed of 93 wedges, of which 91, including the key-stone, are of equal thickness,—as seen in Plates XVII. and Fig. 1, XIX., whilst the remaining two at the springs are larger; their thickness being determined by the radius which meets the upper or apparent arch at the point where it springs from the convex part of the abutment. The key-stone is 4.9212 feet deep.

Upon the courses of the abutment from which the *ugnature* spring rest ten other horizontal courses, the upper surface of the last or superior one being level with the extrados of the key-stone, immediately surmounting which is a plain cornice with modillions cut in the solid stone, similar to those round the Temple of *Marte Vendicatore* at Rome*, (as seen in the cross section of the cornice, Fig. 4, Plate XIX.) This cornice is continued beyond the pilasters of the abutments in a plain band without modillions.

The upper line of the cornice marks externally the level of the footpath and centre of roadway; above this is a solid plain parapet rising perpendicularly from its base, and terminated by a corona; its total height being 3 feet 4 inches.

The roadway over the arch is 40 feet wide between the parapets: of this width each of the footpaths occupies about 5 feet, and the carriage-way 30 feet; but over the abutments the width is increased to 88 feet by their convex form, and at the approaches the roadway between the parapets of the advanced body of the walls is 144 feet wide, forming at each end of the bridge a *piazzetta* or open ornamental approach.

The style of the architecture and the nature of the materials give to this bridge a noble and simple grandeur, and a character quite unique; and as a work of art it surpasses all structures formed on similar principles, and is far superior to the bridge of Rialto, built by Michael Angelo, which, though only having a span of 98.6 feet and 23 feet rise, was when erected and long after reckoned a masterpiece of work on account of its flatness.

If I may be allowed to express an opinion, the general architectural appearance of the bridge over the Dora would have been improved, if a simple projecting base had been given to each of the pilasters of the abutments, with its summit forming a line a little above the water level. By this addition a better proportion would have been maintained between the width and height of the pilasters, and a more strict accordance with the cornice that surmounts them. This method is now generally employed, with the best effect, in every great

* See Palladio, Book IV. Chap. VII. Ed. Lond. 1738.

work of the kind, and particularly in this country, which possesses some of the most magnificent structures of the same nature, particularly over the river Thames.

I shall now proceed to examine the particular reasons which determined the engineer to propose and adopt such a structure, as well as to explain the accurate nature of the processes which he employed for the construction of a work, in which the boldness of the design is equalled, if not exceeded, by the excellence of the execution.

In planning the proposed bridge, the engineer had to keep in view the following points: 1st, That it was to be erected over a river of considerable width, and during floods, to which it was subject, of great velocity; 2d, That it was to correspond in its proportions with the main road over the Alps, one of the great thoroughfares into Italy; and 3dly, That it was to adorn the approaches to a capital city of considerable magnitude and beauty.

The nature of the river and the oblique direction of its bed, relative to the axis of the main road at the entrance of the town, were the first difficulties to be surmounted, and the engineer at once conceived the necessity of making a new branch road through the suburbs, and of constructing the bridge of a single arch. He perceived the impediments and bad effects that an oblique bridge of three small arches would produce, having the piers also oblique to the stream, or even one of a single arch of larger span in a very oblique direction; he felt convinced too that the art, although not of recent origin in Italy*, does not afford to this day proper means of executing such a work satisfactorily on a very large scale.

Nor could he adopt the plan of an arch perpendicular to the axis of the stream, without deviating from the straight line of the branch road which he had already projected from the centre of the town, which was designed to cross the suburbs, pass over the bridge, and continue on the opposite bank; nor without also being obliged to form such angles as would endanger the safety of travelling vehicles.

He could not therefore adopt any other scheme than the one described, convinced, that where solidity, beauty, and convenience in a work of public utility are alike required, no secondary considerations ought ever to influence any one who undertakes the direction of such a national enterprise, in which are involved the reputation both of the artist and his country.

* The art appears to have been known there as early as 1530, when Nicolò, called "Il Tribolo," erected a bridge of this kind over the river Mugnone, near Porta Sangallo, at Florence, on the main road to Bologna. See Vasari, Vol. XI. p. 308, edizione di Milano, 1811.

The required section of the water way having been first established, an arch of the span above mentioned was resolved on, having its elevation restricted to that of the level of the main road. Every part of the structure was then projected on the soundest calculations of strength, and all the directions to be observed during the execution of the work were specified, so that it might be completed in the most accurate and satisfactory manner, and with the strictest economy both of time and money.

Preparatory to laying the foundations of the abutments on the shore, dams were constructed in front of their position, which being first drained by an artificial channel, the soil within them was excavated to 6.71 feet beneath low water mark, and the surface reduced to a perfect horizontal level:—piles of oak, 12 inches thick, varying from 30 to 40 feet in length, and each furnished with an iron shoe of about 16 lbs. weight, were then placed from 3 to 4 feet from centre to centre, as shewn in Plate XVIII., and driven vertically through the strata, after which their heads were cut in a horizontal plane. These piles were driven by a rigging pile engine, having a monkey weighing 8 cwt. worked by 25 to 30 men, and thus 200 men were employed at the same time on each bank of the river. The depth of the foundations of each abutment is 40 feet, with a counterfort at the sides 20 feet by 10,—as shewn in Plate XVIII. and Fig. Plate XIX., taken at the level of the springing of the arch.

Piles were also driven in for the foundations of the circular parts of the abutments and of the advanced body of wall forming the approaches, in which a space of 18 feet diameter was left for the construction of an arch,—as shewn in Plate XVIII.

Sills of oak 12 inches by 10 were then laid down upon the piles in tranverse and longitudinal directions, as shewn in Plate XVIII., and spiked down to them: all the spaces between the transverse sills were then filled with broken ballast immersed in moderately liquid cement of lime and ceroso *, in the proportion of about equal parts in weight: this mass filled all the interstices left between the sills, and rose to a level with their tops.

Upon this was then laid the first course of the foundation, consisting of granite blocks 1 foot 9 inches in thickness, on which were continued three similar courses with two offsets of one foot, and over these were placed five other horizontal courses, each 2 feet high, constituting the face of the abutments,

* Ceroso is formed of tiles baked, pounded up in a mill, then passed through fine sieves, and just before using well mixed with lime in the proportion above mentioned.

and the uppermost forming the resting points of the spring of the arch:—lastly, seven other horizontal courses were superadded at the circular and rectangular portions of the sides.

At this stage the masonry work was stopped, and left to settle for a whole season, in order to take the consistency necessary for sustaining the lateral thrust of the intended arch.

In the meantime, for the purpose of ascertaining with great accuracy, the cut of the voussoirs, or arch stones, and the disposition of the timber forming the centres, and to facilitate the work in all its details, a platform of about 5,000 square feet was laid down, its surface being perfectly plane and level; and upon this was drawn the projected segment of the arch, together with that of another arch for the construction of the centres, of which the versed sine was 18.9015 feet. The arcs of these segments were drawn by means of points determined on the platform by dividing the respective chords into small equal parts, and finding the length of their corresponding ordinates by calculated tables. Thus was avoided the inaccuracy liable to arise from the very great length of the radius had they been described from a centre.

The centres of the two arches being determined, the disposition of the timber to be adopted for the centering was drawn on the platform in full size, and from these tracings all the timbers were prepared and shaped; the requisite operations for placing the different pieces forming a rib being facilitated by circular wooden rollers of equal diameter, which, moving on the platform, sustained the timbers at a certain height above it.

When the timbers had been thus adjusted exactly over the lines drawn on the platform, each was conveyed to its destined place, and fixed to its position by proper mortices and tenons; and while twenty carpenters were thus employed in constructing a rib, twelve others were putting up one already finished and requiring no farther alteration. Thus was completed in 45 days the whole workmanship and fixing of the centering, consisting of 10 equal ribs, each rib being composed of 3 courses of timber, bound at the joints by straps and keys of iron.

Two timbers were then placed upright close to the abutments, and three piles were driven into the ground in the middle of the river and crossed by three horizontal ties; the two upper ones supporting stays which strengthened the ribs. The ribs were bound together by twenty horizontal double timbers, fixed by proper plates, straps, and bolts; which with all other particulars will be best understood by reference to the first Figure of Plate XIX.

Upon the platform was drawn also, by means of the tables before mentioned, the segment forming the exterior arch, and those horizontal courses of the abutments with which the voussoirs are connected; and in order to obtain the greatest precision in the cut of the wedges composing the two faces of the arch, which wedges harmonize angularly with the horizontal courses, and at the same time to verify their position on being placed, two tables were calculated, in one of which was noted,—first, the exact dimension of the principal arch;—secondly, the abscisses measured on its chord;—thirdly, the corresponding ordinates;—and fourthly, the tangents at the extrados of the key-stone. The other table contained the same particulars calculated expressly for the face of the exterior or upper arch.

On the tracing of the arch drawn on the platform were constructed the wood models for cutting the stones, but as the wedges at the imposts and the intersections of the *ugnature* with the convex part of the abutments were to form part of the horizontal courses of the abutments, the models for those could not so well be determined in this manner; these wedges were therefore formed upon a special model made for the purpose, upon a scale of 1 to $33\frac{1}{3}$. In cutting the voussoirs a small temporary prism was left projecting on the lower face of each, as seen in Fig. 1, Plate XIX., so that when placed in their position, the base of this prism was the only part of the stone that came in contact with the centering on which it rested.

In laying the body of the arch, the engineer deviated from the usual practice of setting up a service bridge or gangway upon the ribs composing the centering, but had small bridges constructed on each side and independent of it, though connected with each other. These bridges were of a width only sufficient to admit of the stones being moved along them, and the flooring of each being formed in two inclined planes, tangents to the curve and meeting at the centre, the stones were dragged on rollers by means of capstans acting at the highest point of the service bridge, till each stone attained the level at which it was to be laid, and then was suspended by the following mechanism, and placed in its final position.—

On the side next the centering of each of the service bridges, vertical timbers were erected at convenient distances, and supported by inclined props or stays, all the props on one service bridge being connected with the corresponding opposite ones on the other by strong horizontal beams that crossed the width of the bridge. Upon these last were laid longitudinal timbers, which

served to sustain a moveable beam, that could be adjusted and fixed in a position to be over the place at which each wedge had to be ultimately laid. Pulley blocks were then attached to this beam so that they could run along it, and by means of ropes and a corresponding apparatus of punks, &c., the wedges were lifted up by a capstan situated behind each abutment. With such a mechanical power acting from the extremity of the bridge, two masons only on the centres, assisted by a few workmen and labourers acting at the capstans, were able to place, in one day's work, about nine wedges, weighing upon an average 5 tons each, and the whole 651 wedges composing the arch, and weighing together 3250 tons, were placed in the space of seventy-five days. It should be observed, that the course of the keystone is formed of 7 wedges, as seen in Fig. 2, Plate XIX., the two outer ones being not less than 8 feet in thickness. Near one-third of the whole number of wedges weighed about 8 tons each, and those composing the first course at the springs, from 15 to 18 tons; and the whole of these enormous blocks were placed without the smallest accident to the workmen employed, or injury to the blocks themselves.

Theory shows, and it has been proved by trial on a small experimental arch, as well as by observation on the subsidence of arches of limited dimensions built by Perronet and other scientific men, that in this kind of structure the settling down takes place by the descent of the parts about the centre of the arch, and the pressing of the joints of the wedges at the intrados near the springs and at the intrados near the keystone, and consequently if the general pressure that must ensue on removing the centres, and in the subsequent settlement is not properly guarded against, it will chip off the edges of the voussoirs, and might very probably be followed by accidents of a far more serious and fatal nature. The engineer Boistard, to avoid those inconveniences in building the bridge of Nemours*, which is only 72.30 feet span, and 7.20 feet rise, had the wedges or arch stones cut somewhat smaller than they would have been, had the intended segment been divided by the determined number of wedges. He supposed that in removing the centres the voussoirs would not come quite close to each other, and directed them to be so placed that the intervals between the joints should vary in the direction of the intrados according to the terms of a decreasing progression from the spring to the key, and consequently in an inverse progression in the direction of the extrados.

* Buzani Antologia di Firenze.

But the engineer Mosca, in planning the bridge over the Dora, supposed, and with truth, that on removing the centering, the voussoirs should come completely in contact, and consequently he directed them to be cut exactly equal to an arch of the span of 147.63836 feet, and a versed sine of 18.04468 feet, and in the framing of it, as we have already mentioned, an arch was adopted for the centering, of the same span, but with a versed sine of 18.9015 feet, and decreasing proportionally to the springs where it intersects with the real segment. He directed also that the joints, instead of being on the projection of the radius to the centre of the arch, as is too generally the case, should be so placed as to have the faces of contact of those near the springs diverging between themselves at the intrados in a decreasing progression proceeding from the impost, and of those near the centre diverging at the extrados in a similar progression proceeding from the key-stone. It is proper to state, that as the difference between the real arch and that adopted for the centres, was not of sufficient magnitude to enable the workmen, in so great a number of wedges, to establish the spaces between the joints according to the calculated progressions, in terms that they could physically appreciate during the erection, the engineer adopted the practical means of dividing the arch into three parts, and directed that in the lower, the joints should diverge near the intrados, that the voussoirs should be placed parallel in the second, and that in the last or upper they should diverge towards the extrados.

During the operations on the platform, the cutting of the arch stones, framing the service bridges and centres, with the superstructure of timbers for lifting and setting the voussoirs, the masonry of the abutments acquired the necessary consistency, and it was then judged proper to proceed with the construction of the arch.

In order to be able to rectify the position of the wedges by means of the calculated tables, an horizontal beam was placed below the arch in a steady position, independent of the centres, upon which were marked the abscisses; and the ordinates of the arch were designated upon two vertical timbers, established like the horizontal one, in an independent and steady position near the abutments.

The placing of the arch-stones was then begun, and carried on in the manner before mentioned, and with all necessary precautions; and besides those generally employed, the following peculiar process was put into practice.

The courses at the spring of the arch were first set; these were connected by crochets to each other, and to those of the face of the circular sides of the abutments which rise above the spring of the principal arch of the faces, viz. up to the twelfth horizontal course; they were then cut and disposed in such a manner as to form the required angles at the *ugnature*, and at the meeting of the convex surface of the abutments with the face of the arch. After each course had been placed with the greatest nicety, their exact positions were verified by means of the abscisses, and the corresponding ordinates marked out on the horizontal and perpendicular timbers, and the inclination of each was properly ascertained. The next proceeding was to place the remaining courses of wedges; and in order to obtain with the greatest exactness the divergence of the joints between each voussoir, and to hold them in their required positions till the lowering of the centres, small plates of lead of a thickness determined by the terms of the fixed progressions were placed between those towards the impost at the intrados, and those towards the key-stone at the extrados, and the exact position of each was verified by means of the practical method established for finding the ordinates. With respect to those voussoirs forming the centre part of the arch, they being somewhat smaller than those of the faces, and of various lengths, small iron wedges were introduced between the joints to hold them in their desired diverging positions instead of the leaden ones. The work of setting the arch-stones being completed with the prescribed accuracy, and the final position of each voussoir being progressively rectified according to the detailed directions, the intervals left between the wedges were filled with a moderately liquid cement of lime and clean sand, mixed in equal parts, which was retained by a slight stuffing of tow, introduced at the lowest part of the aperture of each joint; the iron wedges were then taken away, and in order to ascertain the depression which would take place in the arch on removing the centres, another ingenious yet very simple and precise method was adopted.

A horizontal line was drawn over the total length of each face of the arch, forming a tangent at the intrados of the key-stone, and on each side of the key-stone an oblique line was drawn, starting from a common point at the centre, and tangential to the faces of the exterior arch forming the *ugnature*.

By means of those three lines drawn on each face of the arch, the least motion of the wedges, or voussoirs, would have been observed and deter-

mined, upon referring them to the established points of level near the impost of the arch.

Besides all these precautions, the engineer, before removing the centres, directed that the cement should be scraped off all the joints of the arch-stones at the extrados as well as at the intrados to the depth of three centimetres, to prevent, in the settling of the arch, any chipping off the angles of the faces of the voussoirs: these spaces were again filled at the conclusion of the work.

All these operations being completed, and twenty days having elapsed from that on which the arch had been keyed, the lowering of the centres was begun. On removing the check pieces, the 240 wedges supporting the centres commenced with an almost simultaneous movement gliding down uniformly and insensibly, by the effects of the gravity of the arch-stones and centres; and this motion was checked and repeated at intervals, until the arch was left in equilibrium; and thus the arch-stones, elevated 18.9015 feet at the key, descended with the greatest regularity to 18.40 feet in the space of five days, that being the time employed in removing the centres, and a beautiful curve was preserved, leaving at this period the difference of $4\frac{2}{5}$ inches between the existing arch and the projected one. The engineer, having proved the perfect accuracy of the work and the solidity of the arch, and wishing, moreover, to give it the greatest degree of settlement of which it was capable, and of obtaining a mass absolutely stable, that would enable him to work its spandril walls, cornice, parapet, &c., in a perfect level line, directed the arch-stone to be loaded with a mass, formed by a cube of ballast of 1854 metres and weighing about 3000 tons, which was disposed symmetrically over it, and was much beyond what the arch when completed, with all the additional stone-work and its greatest occasional loads, would ever have to sustain. This weight was left upon the arch for the space of four months, and the sinking under it amounted only to $1\frac{3}{5}$ inch (4 centimetres), leaving the difference in rise above the projected segment $2\frac{4}{5}$ inches (about 7 centimetres).

After this trial, continued through such a space of time, the arch still kept its perfect curve, and not the least alteration was observable in any part of the structure. The engineer, now considering his arch solidly settled, and in a state for continuing the works for its completion, directed the placing of the horizontal courses to be proceeded with, viz.:—those of the face or spandril, which join the extrados of the voussoirs of the arch, and those to complete the abutments, which were terminated by an inclined plane of 1 in 35, starting

from the extrados of the key-stone towards them,—as shewn in Fig. 1, Plate XIX.

As soon as these operations were terminated it was verified that the upper side of the last course of the faces of the bridge was perfectly level with the extrados of the key-stone, throughout the whole length of the bridge and approaches.

The blocks of the cornice were then placed in a horizontal position, and the whole surface of the arch-stones, abutments, and counterforts were covered with a stratum of bituminous cement of the thickness of 0.15 metres, well beaten till it became very hard; then upon this another stratum of 7 centimetres was laid, mixed with fine gravel, and beaten smooth without the least crack; by this coating of cement the filtration of rain-water was completely prevented. This operation finished, the space up to the level of the road was filled in regular and even strata; and when the whole was well settled and reduced to the prescribed form, blocks for the footpath were laid down with a very slight inclination towards the roadway, and defended by truncated conical stones, as seen in the superstructure of the bridge in Plate XVIII., and the paving was put down, consisting of a stratum of sand and gravel, of the mean thickness of 15 centimetres, and covered with a stratum of sand of 0.05 centimetres; then were put up the blocks forming the parapet and its crown—as shewn in the cross section of the cornice, &c., in Fig. 4, Plate XIX.

It is to be observed that no blocks less than from 8 to 9 feet in length were employed for the cornice and parapet, and some of those used in the latter at the abutments were as large as from 36 to 40 feet in length.

When every thing was thus completed, the most minute defects were corrected, and all parts of the structure were minutely dressed; the cement of all the joints of each face, and every part of the bridge exposed to view, was scraped off to the depth of 3 centimetres, and washed with lime; afterwards, all those parts which had been scraped were filled with a cement expressly prepared, composed of one third part of fine powder of marble, one third of fine powder of the same granite used in the bridge, and one third of lime, with a very small quantity of iron filings, well mixed and rubbed together, till it had acquired a sufficient consistency. As soon as this cement was put into the joints, the masons were directed to apply a straight edge to them, with a groove cut in it just the width of the joints, which were of two millimetres in breadth, and through this groove to rub over the cement with an iron point till it became as hard as the stone itself.

In concluding the description of this work, I should mention particularly, that all the blocks of the arch-stones, the face of the wall and the approaches, comprising the cornice, bands, footpath, parapet and crown, are of the best Alpine granite, of the quarry called Del Malanaggio, near Pinerolo; and the faces exposed to view being finely dressed, every other face of contact of each outer block employed was dressed to equal fineness over three fourths of its surface. A small quantity of granite from the quarry of Cumiana, was also used, but only as backing, in the foundations and abutments *. The first kind of granite is the best, and is susceptible not only of being dressed very finely, but also of being used in very small and delicate work, and takes besides a very high polish; the second kind is harder but more brittle, and contains many particles of iron, on account of which its surface, when exposed to the atmosphere, becomes spotted, which gives it a very disagreeable appearance, as may be observed in the bridge near Turin over the Po.

Finally, I have to state that this bridge was constructed in the space of four years †, under the immediate direction of the Chevalier Mosca, principal engineer, well seconded by his able assistants, and with such perfection and nicety, that to this day not the least settling has taken place in any part of the abutments or arch, nor the smallest crack, or chipping of the angles of the voussoirs or of any other block; and as the whole face of this work has been finely dressed, it appears now to the most experienced and practised eye a single solid mass of granite.

Indeed it is considered a noble structure and a perfect piece of workmanship by all professional men who have seen it, whether natives or foreigners.

It may be concluded from the foregoing observations, that the results obtained in the construction of this bridge are entirely conformable to those experienced in arches of limited dimensions, and thence that it may be freely asserted, that the theory of the equilibrium of flat arches remains no longer doubtful, and that a sure process for their construction has been satisfactorily ascertained.

* Cubic specimens of these granites are deposited in the Institution of Civil Engineers, with their faces dressed to the same degrees of fineness as the stones employed in the work.

† The above four years was the actual time employed in building this bridge; for the work was abandoned by the contractor about three years from its commencement, and after the lapse of some time, was taken up solely by the engineer and assistants; and brought to a termination very satisfactory, combined with the greatest possible economy; the bridge, comprising the approaches, having cost the Sardinian government the sum of £56,000.

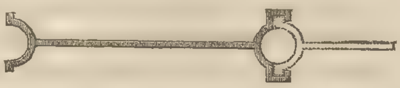
XXII. *Memoir on the use of Cast Iron in Piling, particularly at Brunswick Wharf, Blackwall. By Michael A. Borthwick, A.Inst.C.E.*

A short sketch of the introduction and use of cast iron in piling, may not be considered an inappropriate accompaniment to an account of one of the most recent works in which it has been adopted.

Public attention was first drawn to such an application of iron by Mr Ewart of Manchester, now of His Majesty's Dock-yard at Woolwich; but though this merit is certainly due to that ingenious gentleman, he had been,

Mr Mathews's plan.

as it afterwards proved, anticipated in the idea by the late Mr Mathews of Bridlington, who, previously to the date of Mr Ewart's patent, had used cast iron sheet piles in the foundations of the head of the north pier of that harbour. These piles were of different forms; in the margin is given a cross section of one of, I believe, the most common, in which it will be seen the adjoining piles dovetail to each other, while in others, I have been informed, they merely overlap. Their length was about 8 or 9 feet, their width from 21 inches to 2 feet, and their thickness half an inch.



Mr Ewart's plan.

In ignorance of Mr Mathews's proceedings, Mr Ewart, in the beginning of 1822, took out a patent for a new method of making coffer-dams, which he proposed to effect by employing plates of cast iron, held together by cramps fitted to dovetailed edges on the piles. A section of these piles, taken from some that have been used, is shewn in the accompanying sketch. A detail of the mode in which it was proposed to combine them so as to form a coffer-dam might be out of place, in a paper that has reference more to the use of iron piling for permanent purposes;—the plan, as described in the specification of the patent, is to be found in the Repertory of Arts, and an abstract of it in the London Journal of Arts and Sciences for the year 1822.

The length of the piles is therein stated as intended to be from 10 to 15 feet, which is, I understand, about what they have generally been made, and for cases requiring a greater depth, a mode is described of lengthening the piles, by placing one above another, and securing the horizontal joints by means of dovetailed cramps.

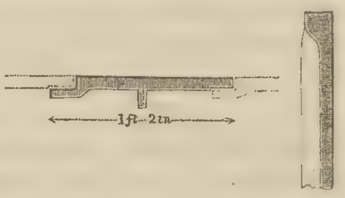
Though on being apprised of what had been done at Burlington, Mr Ewart did not defend his patent, his piles have been pretty extensively adopted, particularly by Mr Mylne of New River Head, London, and Mr Hartley of Liverpool. Besides other operations in the important public work under his charge, the former gentleman used the piles, soon after their invention, with complete success in a coffer-dam of considerable size, constructed in the River Thames for the purpose of putting in a suction pipe opposite the New River Company's establishment at Broken Wharf. They have also been used with advantage by Mr Hartley, in founding the pier heads of the basin of George's Dock, and various parts of the walls of some of the other docks at Liverpool, as also in putting in the foundations of the south river-wall.

Looking at the dovetailed form of these piles, one would, I think, have been inclined to anticipate difficulty in driving them, but this does not seem to have been met with to any extent in practice, at least in coffer-dams, the original object of the invention. On this point I have pleasure in being able to quote some observations of Mr John B. Hartley, which contain the results of the Liverpool experience:—"Considerable care," he writes, "is required in keeping the piles in a vertical position, as they are apt to shrink every blow and drive slanting. They require to be driven between two heavy balks of timber to keep them in a straight line, as they expose very little section to the blow of the ram, and are so sharp that they are easily driven out of a right line. There is another very necessary precaution to be taken, which is the keeping of the fall in the same line as the pile;—otherwise the ram descending on the pile and not striking it fairly, all parts equally, the chances are that, if in a pretty stiff stratum, the head breaks off in shivers, and the pile must be drawn, which is sometimes no easy matter." He concludes by saying, "these piles are on the whole the most useful tools you can use for their purpose (coffer-damming). I believe they have had as extensive a trial at the Liverpool Docks as any where else, and certainly with success. They have generally been driven with the ringing or hand engine and rams of 3 or 4 cwt., a front and back pile being driven at the same time by one ram."

In the work at Broken Wharf, the practice was to insert the piles and cramps all round the dam first, and drive them a moderate distance into the ground,—then to pass the engine repeatedly round and send them down gradually, instead of driving them home at once; and Mr Mylne has mentioned to me that while this was in progress, the piles being at the time but slightly driven, he was somewhat alarmed one morning at finding that the run of the water had elevated one end of the dam considerably above the other. The dovetails however held good, and proper precautions being taken, the return of the tide put all right again without at all crippling the work, the movement having been regular all over the dam. I ought to add that these dams are still used in the works on the New River, four sets being generally kept in hand, and that the ringing engine is always employed, and the above stated method of driving followed.

I have perhaps dwelt longer on Mr Ewart's project than I should otherwise have done, from a feeling that from his labours has sprung much that has followed in the way of iron piling; and besides, it may be observed, the remarks as to driving are not entirely limited in their application to this particular description of pile. The next work that occurs was executed by Mr Walker in 1824; this was the rebuilding of the return end of the quay-wall of Downes Wharf, Saint Katherine's, which had been undermined by the wash from the Hermitage entrance of the London Docks. With a view to a more effectual resistance of a like action in future, iron instead of wood sheet piling was introduced in the foundation of the wall in question; and though, if one may judge from the specification of the patent, no application of his plan of so permanent a nature seems to have been contemplated by Mr Ewart, the work was begun according to it, but it was afterwards modified at the request of the contractor, so as to give the section of pile shown in the margin, the flanch being in front or outside. Although, as has been already seen, the piles in their original form may be easily enough driven in some cases, it was found impossible to get them down in a regular line to the depth required in the present instance, through the hard material that had to be pene-

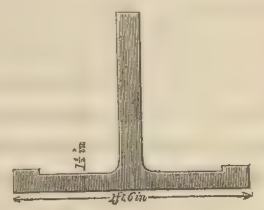
Mr Ewart's plan modified.

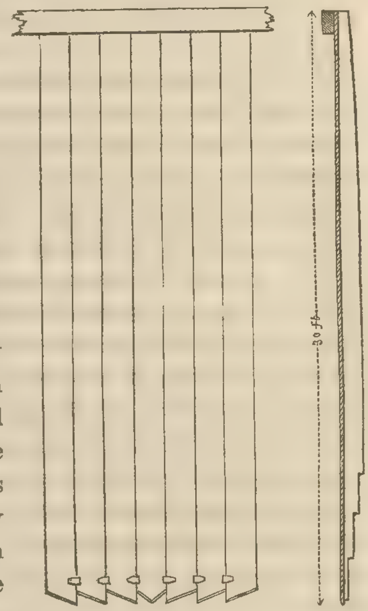


trated, and by which in fact they were surrounded and pressed for nearly their whole length of 14 feet.

Mr Cubitt's plan.

A work on a much larger scale than any yet mentioned now presents itself,—the wharfing at the sea entrance of the Norwich and Lowestoft navigation. In this Mr Cubitt has adopted sheet piling exclusively without the intervention of main or guide piles; the form and section will be seen by the accompanying sketches, which it is almost unnecessary to observe are not drawn to the same scale, the transverse section being considerably enlarged beyond the other two. The piles are all 30 feet long; their weight is about a ton and a half each. The back flanch which is shewn at the deepest on the cross section, tapers gradually to about 6 inches at top, where the angles are blocked in to form a head for driving, and is diminished at the lower end by steps or *sets-off* of parallel width with square ends, instead of a straight or curving line, as the latter shape was found to have a tendency to press the pile forward, whereas by the plan adopted, it drove as fairly as if the flanch had been continued its full width to the foot of the pile. The driving was all effected by means of crab engines with monkeys about as heavy as the piles, no more fall being allowed than was necessary to send them down, and the whole is secured by land-ties, two in height, at intervals of six feet. The entire length of wharfing thus constructed is about 2,000 feet.



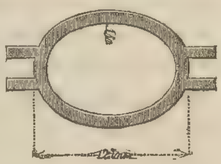


From the form of the pile, according to this plan, giving so thin an abutting surface, and the joints not being covered in any way, close and accurate driving seems essential to its efficacy, and the nature of the ground (sand mixed with

shingle) would have made this a somewhat troublesome operation at Lowestoft, but for the plan that was taken to ensure precision. This consisted in riveting close to the lower end of the pile about to be driven, a pair of strong wrought iron cheeks projecting beyond the edge about two or three inches, which clasping the pile already driven, served as a guide or groove to keep the piles flush, however thin the edge*, and the tendency to turn out or in at the heel was counteracted after a few trials by giving a greater or less bevel to the front or back face. With these appliances the piling was pretty closely driven, and the work, which was completed in 1832, has been found fully to answer the object of supporting the sides of the cut from Lake Lothing to the sea against the effects of the very ingenious and powerful sluicing apparatus provided in the lock at that place.

Mr Sibley's plan.

About a year later than the above, Mr Sibley constructed an iron wharfing on the Lea Cut at Limehouse on an opposite principle, sheet piling being in this case altogether discarded, and the work consisting of flat plates let down in grooves on the sides of guide piles of an elliptical form according to the section opposite, driven at distances of 10 feet. These piles are 20 feet long, weigh about $1\frac{1}{4}$ ton each, and are 9 feet apart; they are hollow throughout, to enable a passage for them to be bored in the soil by means of an auger passed through them, and so ease the driving, and are filled with concrete; each pile is land-tied, and the plates extend to within 6 feet of the point. A similar wharfing, but on a larger scale, has since been made on each side of the Thames, adjoining New London Bridge; that on the City side rather an extensive work, the piles in it being 43 feet long, (cast in two unequal lengths with a *spigot and faucit* joint,) of a cylindrical form, 12 inches diameter, and of metal $1\frac{1}{2}$ inch thick, and each pile being secured by two tiers of ties of 2 inch square iron carried 70 or 80 feet back, to resist the great depth of filling up or backing.



The plan just described seems well enough adapted for situations where any great increase of depth is not likely to take place. The absolute depth is not so important, though where this is considerable, it may be questionable whether a

* This plan has, I believe, been followed by Mr Cubitt in driving timber piling also, in cases requiring nicety of work.

heavy wharf would not be the better for the protection of a continuous row of piling at foot;—the strong land-tying necessary in the last mentioned work seems to point to this.

Brunswick Wharf.

I now come to the quay wall constructed in 1833–4 by Messrs Walker and Burges on the River Thames, in front of the East India Docks at Blackwall, and since named Brunswick Wharf. The object of this work was to afford accommodation for the largest class of steam-vessels at all times of tide, for which the old quay, even had it not been in a state of decay, was not adapted from the shallowness of the water in front of it. To effect this, the first idea was to run out two or three jetties from the wharf, but this was soon abandoned, and a new river-wall resolved on; and advantage was taken of the occasion to improve the line of frontage by an extension into the river, under the sanction of the Navigation Committee of the Port of London, varying from a point at the east end to about 25 feet at the other extremity. The use of iron in the work was, I have understood, suggested by Mr Cotton, deputy chairman at the time, and for many years an active member of the most respectable and liberal body then in the direction of the East India Dock Company, and the adoption of the proposal was facilitated by the circumstance which probably led in the first instance to its being made, namely, the low price of the material at the period, the contract being little more than £7 per ton delivered in the Thames.

In the accompanying drawing, plate no. XX, an attempt is made to show the mode of construction that was followed, so as to avoid the necessity for much written detail. The first operation was to dig a trench two yards deep in the intended line, and this was immediately followed by the driving of the timber guide-piles. The deepening in front, which to give the required depth of 10 feet at low water, was as much as 12 feet, was not done until near the conclusion of the work;—to have effected it in the first instance would, without any countervailing advantage, except some saving in the driving, have been attended with the double expense of removing the ground forming the original bottom between the old and new lines of wharfing, and afterwards refilling the void so left by a material that would require time to make it of equal solidity; and even if this had been otherwise, such an attempt would have endangered the old wall, or rather would have been fatal to it. The permanent piling was next begun, the main piles being driven first at intervals of 7 feet, and the intermediate spaces or *bays* then filled in, working always from

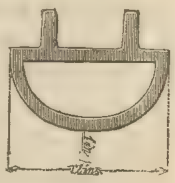
right to left, towards which the *drafts* of the sheet piles were pointed. The ground is a coarse gravel, with a stratum of the hard Blackwall rock occurring in places, and some trouble was occasionally experienced from its tendency to turn the piles from the proper direction, but due attention being paid to the form of the points, the driving was on the whole effected pretty regularly, but few of the bays requiring closing piles specially made for them, so that the work may be said to be nearly *iron and iron* from end to end;—at the same time, the vertical joints of the piling being all covered, as will be noticed presently, any slight imperfection in this respect is no serious detriment to the work as a whole.

The main piles are in two pieces, the lower end of the upper one being formed so as to fit into a socket on the top of the under length, and the joining made good by means of a strong screw-bolt;—the only object of this was to insure a supply of truer castings, and lessen the difficulty of transporting such unwieldy masses from Northumberland and Staffordshire to London*. Each sheet pile is secured at the top by two bolts to the uppermost wale of the woodwork behind, and the edge of the end ones of each bay, it will be observed, pass behind the adjoining main pile, while the other joints are overlapped by the *bosses* with which all the sheet piles except the *closers* are furnished on one side. Besides adding to the perfection and security of the work by breaking the joints, so that the water (if it penetrate, as with even the best pile-driving it will,) cannot draw the backing from its place, these projections appear to me to relieve the appearance of the otherwise too uniform face; and a like effect is produced by the horizontal fillets on the lower edges of the plates above, which also mask the joints. These plates, filling up the spaces over the sheet piling, are bolted to the main piles and to each other in the manner shown, and the joints stopped with iron cement. Where the mooring rings come, the plates are cast concave, with a hole perforated in the middle to allow a bolt to pass through, and this bolt is secured, as well as the land-ties from the main piles, to the old wharf, which was not otherwise disturbed, or to needle piles driven adjoining it. The backing consists of a concrete of lime and gravel, in the proportion of about one to ten, extending down to the solid bottom. The coping with the water channel in its rear is of Devonshire granite; the water is conveyed from the channel at intervals by pipes, extending from gratings in the bottom in a slanting

* The Birtley Iron Company, Newcastle-on-Tyne, were the contractors for the ironwork, but a portion was supplied by the Horsley Iron Company. Mr M'Intosh, of Bloomsbury Square, had the contract for driving the piles and fixing the work.

line to the lowermost plate, and discharging themselves immediately above the sheet piling.

The main piles were originally proposed to be hollow in section, according to the sketch opposite; but this was given up on further consideration of the uncertainty of procuring sound castings of the intended form, and of the greater liability to break afterwards from a blow sidewise. The solid form shown on the plate was therefore adopted, according to which the lower lengths weighed about 28 cwt.; and that this was not too much was shown by the circumstance of several of the piles, particularly the early ones, breaking in the testing or driving, and showing in the fracture the danger of even a slight defect. The greater care subsequently taken at the foundry, and probably also greater experience in driving, made accidents of this kind of rarer occurrence in the later stages of the work; and it may be mentioned as no bad proof of the care of all parties, that of upwards of six hundred piles, including both descriptions, only sixteen broke in driving, seven being of one sort, and nine of the other :—the failure was in five cases attributed to strains in driving, and to imperfections of casting in the other eleven. The sheet piles, which bear a considerable resemblance in their general outline to those used at Downes Wharf ten years before, were proposed to be an inch thick, but it was found necessary to increase this dimension, and some of them were as much as $1\frac{1}{4}$ inch; the average, however, was not above $1\frac{1}{8}$ inch, and the weight of each pile 17 cwt. The length of the wharf is about 720 feet, and the whole weight of iron used upwards of 900 tons.



The crab engine was employed invariably, the heads of the piles being covered with a slip of $\frac{3}{4}$ inch elm, to distribute the force of the blow equally over the iron, and prevent jarring. The monkeys used weighed from 13 to 15 cwt each, and it was found necessary to limit the fall to a height of 3 feet 6 inches, and sometimes less, when the resistance proved more than usually great and the pile showed a tendency to turn from its straightforward course. The driving throughout was very hard, more especially at the west end, where the sheet piles in four bays could not be forced to the full depth, the space above being in two of them made up with two plates in height, and in the other two admitting only one, instead of three as in the rest of the work. Driving was the only means resorted to, or indeed practicable in the gravelly soil that prevailed. Had the bottom been clay or other similar substance, the plan of boring

to receive the points, that has been followed elsewhere, might probably have been partially adopted in the main piles with advantage; but I should say, certainly not to the extent of depending mainly upon it for getting the piles home to their places.

I cannot quit the subject of the Brunswick wharf without stating that his avocations alone have prevented Mr George Bidder's association with me in the account of a work, the execution of which he had, under Messrs Walker and Burges, the charge of superintending. Though rejoicing at the cause, I cannot help regretting the circumstance in the present instance, as such cooperation on the part of my friend would, I feel, have given this paper an interest and a value it has now but little claim to. I take this opportunity also of acknowledging my obligation to several of the gentlemen above named in connection with the previous use of iron piling, whose kindness has enabled me to make the preliminary review much fuller than I had at one time any expectation of having the power to do.

Effects of water on iron.

It remains for me only, in conclusion, to advert to a consideration that ought not to be lost sight of in deciding upon the eligibility of cast iron wharfing,—I mean the action of water upon it. I do not recollect any observations made so as to enable a practical inference to be drawn from them; but the importance of the subject seems to claim attention, and possibly even this notice may be the means of inducing it from those who have the opportunity. The investigation belongs perhaps rather to chemistry than engineering, but notwithstanding the practical turn some of the most distinguished cultivators of that science have given their researches, little I believe has yet been done to explain the present question. How iron is affected by water in its various states, and in what manner the action on *wrought* differs from that on *cast* iron, are interesting points, still, so far as my information goes, to be determined; and they are not likely to be so in a satisfactory manner, until some one competent to the task calls a series of well conducted experiments in aid, as every day shows more clearly the uncertainty of analogical reasoning, however apparently strict, on such subjects. But whatever the *modus operandi* between cause and effect, that decomposition of the metal, more or less rapid, gradually goes on from the action of water, seems to admit of no doubt. Professor Faraday, in a letter to Captain Brown, says, "Cast iron is certainly liable

to great injury from constant immersion in salt water, and I think you would find few, if any exceptions, provided the water and the iron are in contact." * And the *saline principle*, to use a somewhat antiquated form of expression, though a great accelerator of the process, does not appear to be altogether an essential to it †; at least, I know a case that happened in a part of the River Thames where the water cannot be said to be more than brackish at any time, and indeed is generally quite fresh, in which cast iron, after being immersed for little more than twenty years, was, on being withdrawn from the water, found so soft as to yield to the pen-knife; and the original surface of the iron referred to,—it was the socket-plate to the heel-post of a lock-gate,—had not been submitted to the tool, in which case it is well known the water would have operated with much greater effect.

But though I have thought it well to glance at the above case occurring in water, always except on rare occasions fresh, the sea is no doubt in practice the invader whose inroads are most alarming. Instances might easily be cited in proof of the ravages committed by that active enemy, though not perhaps noted so circumstantially as is desirable, but I am unwilling to lengthen this communication further, and shall therefore confine myself to a passing allusion to the example on a large scale, and after long trial, furnished by the state of the guns taken from the wreck of the Royal George, as described at a late meeting of the Institution ‡; and to a similar instance mentioned by Berzelius, in a passage which I quote at length, not so much however in confirmation of so well established a fact as the eventual decomposition of cast iron by the action of water, as for the properties mentioned of the substance into which the metal is resolved. The extract is as follows:

"Quand la fonte reste long-temps sous l'eau, elle est decomposée; l'acide carbonique contenu dans l'eau dissout le fer et l'entraine; il reste une masse grise qui ressemble à la plombagine. Lorsqu'on retira de l'eau, il y a quelques années, les canons d'un vaisseau qui avait coulé à fond cinquante ans auparavant, aux environs de Carlscrona, on les trouva au tiers converti en une pareille masse poreuse; à peine étaient-ils à l'air depuis un quart d'heure, qu'ils commencèrent

* *Description of a Bronze or Cast-iron Columnal Lighthouse, &c., by Capt. Brown, R.N.*

† The difference between sea and other water, in operating with the galvanic battery, is much less considerable than that between the latter and distilled, but it is between *salt* and *fresh* that the practical question lies in the present case.

‡ *Min. of Convers.* Vol. V. No. 12.

à s'échauffer tellement, que l'eau qui y restait encore s'échappa sous forme de vapeur, et qu'il fut impossible d'y toucher. Depuis, Macculloch a observé * que le corps analogue à la plombagine qui se forme ainsi présente toujours ce phénomène, et que ce corps s'échauffe presque jusqu'au rouge, en absorbant de l'oxygène. Ou ne sait pas précisement ce qui se passe dans ce cas."—*Traité de Chimie*, Tom. III. p. 273.

* The observation referred to by Berzelius in the above, occurs in *Macculloch's Western Isles of Scotland,* (I think in the account of the island of Mull,) where an explanation of the phenomenon was first attempted, though, if on such a subject I may "hint a doubt", not to my mind quite a satisfactory one. A more perfect solution will probably be furnished by whoever, availing himself of the powerful means of chemical analysis now possessed, may undertake such an investigation of the whole question of the action of water on iron as I have ventured to allude to in the text.

XXIII. *An Account of the new or Grosvenor Bridge over the River Dee at Chester.*

[The drawings from which the engravings of this bridge (plates nos XXI and XXII) have been made were furnished by Mr John B. Hartley, son of the engineer under whose direction the edifice was built, and the following account has been derived from a letter from him to the President, accompanying the plans, and other original communications in the possession of the Institution, and partly from the minutes of conversation at several meetings when Mr Trubshaw, the contractor for the work, was present*, while such other trustworthy sources of information as were accessible have also been referred to. The statements, so far as they go, rest therefore on good authority, but the Council cannot help regretting that they are unable on this occasion to present a connected account of the work worthy of its magnitude, directly from the pen of some one of the gentlemen engaged in its construction.

Though the site of the new bridge is quite apart from that of the old one, and the latter exists as before with the exception of being no longer the leading thoroughfare, a short notice of the ancient structure, as supplied by antiquarian writers, has not been considered altogether out of place.]

The old bridge over the Dee at Chester extends from the city to a suburb on the opposite side of the river named Handbridge. The first notice of a bridge in this place occurs in the thirteenth century, during which it is recorded to have fallen down or been carried away twice. Those structures were most probably of timber, but on the second accident alluded to a stone erection seems to have been substituted at the cost of the citizens: this was in 1280, and it does not appear that the bridge has been entirely rebuilt since, though it is mentioned that part next Handbridge was "made new" in the year 1500. The two arches on this side are plainly of later build than the rest; one of them is

* *Orig. Commun.* Vol. IV. No. 9, and Vol. V. No. 16; *Min. of Convers.* Vol. V. Nos. 8, 9, and 13.

in form a segment of a circle, the other is very slightly pointed, while the remaining arches are pointed Gothic. The whole has been repaired and widened within the last few years.

As usual in former days, Chester Bridge was provided with its gates, which remained until towards the end of last century. Each extremity of the bridge was guarded in this manner, and over the gate next the city stood a tower, named "Tyrer's Tower," for raising water from the wheels under some of the arches for the supply of the town: the tower no longer exists, and there is now only one gate, a modern edifice, on the English side of the river, but the waterworks and the weir still remain.

The bridge, thus irregular alike in workmanship, form and dimension, consists of seven arches supported on huge piers or buttresses, and has been aptly and pithily described as "a long fabric of red stone, extremely dangerous and unsightly, and approached by avenues on the Chester as well as the Handbridge side, to which the same epithet may be safely applied." * The inconvenience of a steep and twisting passage of this kind on the main communication between Wales and the centre and north of England, became more felt every day amid the rapidly growing intercourse arising from the improvement of the roads in the principality, particularly that to Bangor and Holyhead, and at length brought about a conviction of the necessity of a new bridge. It was many years, however, before any active measures were taken to carry so desirable an object into effect, nearly a quarter of a century having elapsed between the period when the late Mr Harrison of Chester projected the structure on the site it now occupies, and the beginning of the work; and by this time, from advanced age and declining health, the superintendence of its execution required too much exertion for the strength of that most respectable practitioner, whose works have added so much to the architectural embellishment of his picturesque native city. Under these circumstances Mr Hartley of Liverpool was applied to by the commissioners to undertake the management, which he consented to do on the condition that no alteration should be made from Mr Harrison's external design, but that the interior and all practical points should be left entirely to him. It may be proper to add that Mr Harrison had given two elevations, one having the abutments ornamented with Grecian Doric

* Ormerod's Cheshire, Vol. I. p. 285.

columns, the other having a plain niche with a pannel over it, and that the latter was adopted by Mr Hartley's advice.

The new bridge is situated about a quarter of a mile to the west of or lower down the river than the old one, stretching from the rock below Chester Castle towards the village of Overlegh, with a boldness that appears still more striking if the view be from the low ancient bridge. The valley of the Dee here skirts close round the city, the ground next which rises rapidly, and the road is carried with a slight fall from the castle gate on an embankment, which, after ascending gently over the bridge, is continued across the broader plain on the other side of the river, until it falls into the Flintshire road from the old bridge. The harbour is below the site, but vessels occasionally pass above the bridge, which from its great height offers no obstruction to navigation. The flow of the tide so far up the river is not more than twelve feet in ordinary springs.

The abutments are founded on the solid rock, except the back part of that on the north or city side, where, a fault occurring from the rock dipping down almost vertically as shown on the section, piling became necessary; and so soft was the material with which the fissure was filled, (a kind of quagmire or quicksand,) that the piles went down five or six feet at a blow for a considerable part of their depth. On the head of the piling a floor of stone was laid and the abutment built upon it. In consequence of the defect in the foundation just mentioned it was considered prudent, with a view to keep the lateral thrust of the arch within the limit of the rock, to make the springing a foot lower and the crown as much higher than was at first intended, and this was the only deviation from the original design that took place in the work.

The arch is a segment of a circle of 140 feet radius, the span or chord being 200 feet, and the rise or versed sine 42 feet. The archstones are 4 feet deep at the crown, and increase to 6 feet at the springing, but from the mode followed in laying the masonry, it will be seen that the principle of the arch is carried through the abutments, even down to the foundations, the radiating joints giving place to horizontal ones only in what is comparatively superstructure.

To prevent flushing near the haunches and rectify any tendency to

change of form in the arch on the removal of the centre, the first course above the springers was laid upon a wedge of lead $1\frac{1}{2}$ inch thick on the face and running out to nothing at the extremity of the bed, and strips of sheet lead eight or nine inches wide were also introduced in the joints on each side, up to where the point of pressure was considered to change its position from the front to the back of the archstones, or in fact in the present case over about two-thirds of the whole soffit. This disposition remained unaltered until the easing of the centre let the whole of the arch settle on the lead, which from its yielding nature then caused the pressure to be spread evenly over the whole of the bed of each course, and thereby prevented drafts or openings at the back of the archstone joints; the wedge-piece at the springing also acting by way of adjustment, and counteracting the inclination of the arch in coming to its bearing when the centre is struck to throw an undue weight on the intrados of the springing course. Judging from the soundness of the archstones throughout, this plan seems to have answered fully the end sought, the weight having been received so uniformly and gradually on all points, that not the slightest appearance of *spaulching* or cracking is perceptible in the work of the great arch.

In setting the keystones three thin strips of lead were first hung down on each of the stones between which they were to be inserted, and the keystone being then besmeared with a thin greasy putty made of white lead and oil, was driven down with a small pile-engine, the lead acting as a slide and preventing grating until the stone was quite home.

The mode in which the spandrils were made up internally, by tiers of pointed arches with flag-stones or landings at top to carry the road material, will be seen by a glance at the cross section on plate no. XXI; and indeed beyond what has been already stated, and the materials used, which are now to be described, with the mode of dressing them, there does not seem much of importance as regards the construction of the permanent part of the work which an inspection of the plans will not readily supply.

The river face of the abutments up to the springing, and the first two courses of archstones above, are of granite; the key-course with one on each side of it and the quoins all through the arch are of the limestone known as Anglesea marble, and the rest of the work, including all the other archstones, almost entirely of the sandstone of the country. The granite was

brought from Craignair near Castle-Douglas in Kirkcudbrightshire, the limestone partly from Anglesea and partly from the similar quarries of Wagbur near Burton in Kendale, and the other stone for the outside works from Manley near Northwich and Peckforton near Nantwich in Cheshire, the quarries of both which places produce a superior kind of the new red sandstone. The principal part of the backing is of a similar sandstone, found adjacent to the site of the bridge. The mortar used was made from the lime found in the neighbourhood, mixed with twice its bulk of sand.

The external faces of the bridge and abutments, with the cornices, parapets and dressings, are neatly tooled; the land-arches and wings slightly chamfered in the joints and then scappled off, so as to have a rougher and more rustic appearance. The archstones of the main arch are also chamfered in the soffit joints, two inches on each arris.

The centre on which the stupendous arch of Chester new bridge was raised, and which is stated by Mr Hartley to have been exclusively designed by Mr Trubshaw, claims a detailed notice, from the novelty of the principle it was formed on, the efficiency with which it did its work, and the economy that attended its use. The centre consisted of six ribs in width, and the span of the arch was divided into four spaces by means of three nearly equidistant piers of stone built in the river, from which the timbers spread *fan-like* towards the soffit, so as to take their load *endwise.* The lower extremities of these radiating beams rested in cast iron shoe-plates on the tops of the piers, and the upper ends were bound together by two thicknesses of 4 inch planking bending round, as nearly as they could be made, in the true curve of the arch. On the rim thus formed the *lagging* or covering, which was 4½ inches thick, was supported over each rib by a pair of folding wedges, 15 or 16 inches long by 10 or 12 inches broad and tapering about 1½ inch;—for every course of archstones in the bridge there were therefore six pairs of striking wedges. The horizontal timber of the centre was only 13 inches deep, and the six ribs were tied together transversely near the top by thorough bolts of inch iron, but with a view not to weaken and injure the timber more than was absolutely necessary, the least possible of iron was used.

From this description and an examination of the drawing it will be observed, that the centre differs essentially from those that have been used else-

where. At first sight it reminds one of that employed by Smeaton in building Banff bridge, but the likeness is only apparent. Each rib of the latter is a complete connected frame from pier to pier, though supported intermediately, and is capable of being eased only as one mass by the folding wedges which are placed under and carry it; whereas in the Chester centre each rib is composed of four distinct and independent parts, and carries the wedges on its outer rim instead of being borne by them, so that it can be struck gradually, being made tight at one place and slackened at another, according to the symptoms shown by the arch as its support is removed and the stonework comes to its bearing. Mr Trubshaw's principle is, therefore, in a few words, to arrange the timber so as to have the strain all in a vertical direction, doing away with the necessity of much horizontal tying, which from its sinking he considers apt to derange the framing, and to ease immediately under the covering instead of under the sill of the centre; and with this construction he would strike a centre soon after the arch was finished, while the mortar was yet as it were a paste, easing a little at first and then giving some time for the joints to accommodate themselves, and so proceeding. His method of striking is to keep up the crown and let the haunches down, and though this has a tendency to press the keystone up, he states that he has found a greater and more usual difficulty to be in managing an arch after the key was lowered, as it must be at once and beyond recall with centres of the usual make.

The centre was of fir, and with the exception of the parts already mentioned as otherwise, was composed entirely of whole and half timbers;—pieces from 22 to 36 feet long were not bored with more than one hole, and it of small size, so that, the material being sound when taken out, the whole cost to the contractor was only about £500, an amount which, even allowing for the advantage derived from the accidental circumstance of a quantity of seasoned wood being opportunely required for a public work in the neighbourhood, must still be considered a very low price for a structure requiring 10,000 cubic feet of timber. That the expectations of the projector were fulfilled in other respects also, is proved by the circumstance of half the arch being turned before the centre was finished, while the fact that on its removal the crown sank only from $2\frac{1}{2}$ to $2\frac{5}{8}$ inches, the joints remaining perfectly close and no derangement of form being perceptible, attests the skill and care at once of the carpenter and the mason.

In reference to the temporary works, it seems necessary only further to mention that the archstones were carried to their places by the traversing machine now usually adopted for such purposes, which, though old in principle, it is believed assumed its present form in the hands of the late Mr Rennie, as a means of working the diving bell in his operations at Plymouth. Of the contrivance, though it scarcely requires description in the present day, it may be shortly said, that it consists in suspending the body to be moved to a carriage travelling on a railway fixed on a frame of timber, which frame is itself moved in like manner on a similar railway under and at right angles to it, so that the carriage has a double motion and can be brought over any point within the range of the frames to deposit its load. In the present case the *inferior* railway extended from abutment to abutment, resting on the intermediate piers, and on it travelled two transverse frames of from 45 to 50 feet span, so as to embrace the whole width of the arch; and there being thus a carriage at each end of the bridge, the setting of the archstones did not consume much time.

The Act of Parliament under which this bridge has been built was obtained in the session of 1825; the works were contracted for by Mr James Trubshaw, of Haywood in Staffordshire, early in 1827, and immediately commenced, the son of the contractor being resident throughout; the first stone was laid by the present Marquess of Westminster (then Earl Grosvenor) on the 1st of October in the same year; and the bridge was formally opened on the 17th of October, 1832, by the Princess Victoria, on the occasion of Her Royal Highness's visit to Eaton Hall, and named, at the request of the Commissioners, Grosvenor Bridge, but it was not thrown open to the public generally until New-Year-Day, 1834.

The total cost of the work was £49,900, in which is included a sum of £7500 for the heavy embankments required in the approaches. The money was partly raised by bonds, and partly advanced by the Commissioners for the Loan of Exchequer Bills, and is secured on tolls charged both on the new and the old bridge, the revenue yielded by which is about £3000 a-year.

The following table*, containing the leading dimensions of the largest stone arches that have been built (from 150 feet span upwards), will enable a comparison to be made between the bridge it has been the purpose of this paper to describe, and others approaching but not equalling it in magnitude of arch.

Name.	River.	Form.	Span.	Rise.	Keystone.	Date.	Engineer.
			Feet.	Feet.	Ft. In.		
Claix (Grenoble)	Drac	Circular	150	54	3 1	1611	
Gloucester . .	Severn	Elliptical	150	35	4 6	1827	Telford.
London . . .	Thames	Elliptical	152	$37\frac{1}{2}$	4 9	1831	Rennie.
Tournon . .	Doux	Circular	157	65	......	1545	
Verona . . .	Adige	Elliptical	160	53	......	1354	
Lavaur . . .	Agout	Elliptical	160	65	10 9	1775	Saget.
Gignac	Erault	Elliptical	160	44	6 5	1793	Garipuy.
Vieille-Brioude	Allier	Circular	178	69	5 3	1454	Grenier and Estone.
Chester . . .	Dee	Circular	200	42	4 0	1833	Hartley.

* The dimensions of the continental bridges have been gathered from M. Perronet's *Description des Projets et de la Construction des Ponts*, M. Gauthey's *Traité de la Construction des Ponts*, and Von Wiebeking's *Theoretisch-Practische Wasserbaukunst;* and in the cases of the discrepancies that sometimes occur, (particularly as to the span of the ancient bridge of Vieille Brioude, which is stated to be 183 feet by Perronet, in his bold project for the bridge of Melun, and also as to the rises of some of the other arches,) Gauthey's Work has been preferred, as it seems entitled to be from the character of its talented editor, the late M. Navier, in whose death the Institution has too soon to lament the loss of a valued honorary member.

XXIV. *An Account of some Experiments made in* 1823 *and* 1824, *for determining the Quantity of Water flowing through different shaped Orifices. By* BRYAN DONKIN, *Esq., F.R.A.S., V.P.Inst.C.E.*

THE apparatus employed in these experiments having been made for a different purpose than that of merely ascertaining the quantity of water discharged, occasioned the peculiar form which is here described.

A, in Fig. 1, Plate XXIII., represents a vertical copper pipe of $3\frac{3}{8}$ inches interior diameter.

B, a horizontal pipe of the same diameter, joined to the lower end of *A* by what is usually called a mitre joint.

C, another pipe, joined to *B* in a similar manner, but so contrived that it could be turned up or down into a vertical or horizontal position.

Fig. 2 represents the outer end of the pipe *C*, with a cap, *D D*, fitting closely upon its outer side, and capable of being put on or taken off at pleasure; upon the end of the cap *D* the ring *d d* was soldered, being about $\frac{1}{4}$ inch wide; this cap was employed for securing the different shaped orifices to the pipe *C*. For instance, where the efflux of water through an aperture in a thin plate of metal was intended to be tried, the cap was taken off, and a circular plate *e e*, of a corresponding diameter to that of the exterior of the tube *C*, was applied to the end of *C*, and the cap *D D* put over it to secure it in its place.

To guard against any leakage of water between the joinings of the cap, the pipe, and the plate, the joinings were filled with a soft cement made of tallow and bees' wax.

Upon the upper end of the pipe *A*, a copper cistern, *E*, was fixed. This cistern was about 2 feet diameter and 6 or 7 inches in depth; the length of the pipe *B* was 10 feet; of *C* about 1 foot 9 inches, and of *A* about 25 feet, measuring from the top of *E* to its junction with *B*.

The water was supplied from a circular cistern, *F*, of 6 feet $7\frac{1}{2}$ inches diameter, and 2 feet 10 inches in depth, by means of a sluice *f*, and the trough *g*.

During each experiment a man was placed to regulate the sluice, so as to keep the cistern *E* always full. And in order to ascertain the quantity of water discharged, a float with a graduated stem was placed in the said cistern *F*.

On the 28th of November, 1823, the following experiments were made in the presence of Professor Barlow, of Woolwich.

To the end of the pipe *C*, the conical pipe *G* was applied, by having a thin plate, *h*, soldered to it; the opening at the smaller end, which was $\frac{1}{2}$ inch in diameter, and that of the large end $2\frac{1}{2}$ inches diameter, and its length 12 inches; the discharge took place from the larger end of the cone, whilst the pipes *C* and *G* were in a vertical position; the height of the column of water from its surface in *E*, to the upper end of the cone *G*, was 22 feet 9 inches. In 4 minutes it discharged 12·25 cubic feet of water, being at the rate of 3·0625 cubic feet per minute.

2d Experiment.—The conical pipe was inverted so that the discharge took place from the smaller end; in 4 minutes the discharge was 12·5 cubic feet, or at the rate of 3·125 cubic feet per minute.

3d Experiment.—The conical pipe was removed, and a thin plate with a hole $\frac{1}{2}$ an inch in diameter in its centre was applied to the end of the pipe *C*, the height of the column being 23 feet 3 inches; in 4 minutes the discharge was 8·2 cubic feet, or at the rate of 2·05 cubic feet per minute.

Nov. 29. The pipe *C* and the cone *G* were placed horizontally, with the smaller end of the cone outwards, and a column of 26 feet; in 8 minutes it discharged 26·8 cubic feet, being at the rate of 3·35 cubic feet per minute.

Dec. 1st. Pipe and cone horizontal, the larger end outwards, and 26 feet column; in 5 minutes discharged 15·4 cubic feet, or 3·08 cubic feet per minute.

Another experiment was continued for 8 minutes, and the discharge was at the rate of 3·09 cubic feet per minute.

Dec. 5. Two conical pipes, *H H*, each of which was of the same dimensions as the one above described, were united at their smaller ends, and applied to the pipe *C*; in 10 minutes the discharge through the double cone was 48 cubic feet, or at the rate of 4·8 cubic feet per minute, the column of water being 24 feet 3 inches.

A second experiment on the same day was made with a thin plate, having a $\frac{1}{2}$ inch hole through it, and a column of 24 feet 3 inches; in 10 minutes the discharge was 20·6 cubic feet.

In a third experiment, the double cone was tried again, and the discharge obtained was 47·4 cubic feet in 10 minutes.

Dec. 8. The 2 conical pipes last mentioned were separated, and joined together at their larger ends, as at $J J$; in this form a discharge of 20·8 cubic feet of water was obtained in 10 minutes, under a column of 24 feet 3 inches.

Dec. 12. The thin plate with a ½ inch hole was again applied under a column of 24 feet 3 inches, and during 10 minutes discharged 20·75 cubic feet.

Same day. The single cone with the small end outwards, in 10 minutes discharged 32·2 cubic feet, and with the large end outwards, 29·7 cubic feet in the same time, under a head of 24 feet 3 inches.

Same day. The double cone united at their smaller ends, produced a discharge of 46·5 cubic feet in 10 minutes, and in 5 minutes 23·5 cubic feet.

June 8th, 1824. The discharge through the ½ inch round hole in the thin plate during 15 minutes, was 31·75 cubic feet, under a column of water of 24 feet 4 inches high = 2·116 cubic feet per minute.

June 9. Through the same hole, and under the same column, the discharge was 42 cubic feet in 20 minutes; = 2·1 per minute.

Through a round hole ¼ of an inch diameter, in a thin plate, the discharge was rather less than 16 cubic feet in 30 minutes, under a column of 25 feet 8½ inches.

June 10. The ½ inch hole through a thin plate gave a discharge of 65 cubic feet under a column of 25 feet 8½ inches in 30 minutes, at the rate of 2·166 cubic feet per minute.

The single cone, with the smaller end outwards, delivered 58 cubic feet in 18 minutes, under a head of 25 feet 8½ inches; = 3·22 cubic feet per minute.

On a subsequent day in June. The same experiment repeated, and in 20 minutes the discharge was 63·33 cubic feet; = 3·166 cubic feet per minute. In this experiment, the small end of the cone was immersed about 6 inches below the surface of the water during the discharge, consequently the column was 25 feet 2½ inches.

Another experiment on the same day, with the same cone, having its larger end outwards, and immersed seven inches below the surface of the water, discharged 59 cubic feet of water in 20 minutes; = 2·95 cubic feet per minute.

The same experiment repeated during 10 minutes, gave a discharge of 29·46 cubic feet, or 2·946 cubic feet per minute.

In another experiment, the double cone joined at the smaller ends, in 18 minutes discharged 84·633 cubic feet under a head of 25 feet 9 inches ; = 4·7 cubic feet per minute.

Another experiment. The same double cone with its axis 7 inches under water, and a column of 25 feet 2 inches, discharged 56·5 cubic feet in 12 minutes ; = 4·7 cubic feet per minute.

XXV. *On the Changes of Temperature consequent on any Change in the Density of elastic Fluids, considered especially with reference to Steam. By Mr.* THOMAS WEBSTER, *M.A. of Trinity College, Cambridge. Communicated by Mr.* JAMES SIMPSON, *M.Inst.C.E.*

MY attention having been for some time directed to the theory and constitution of fluids, it has appeared to me that there are some properties of which little notice has been taken, but which, being of considerable practical importance, ought to receive the attentive consideration of scientific men, and especially of those who possess the opportunities of deciding on their value. On the present occasion I beg to offer a few observations respecting these properties. I wish, then, to call attention to the *change of temperature* which always accompanies a *change in the density* of an elastic fluid, and to the consequent change in the elastic force due simply to that change in temperature, as distinguished from the change which is due to the change of density according to the law of Boyle. It has long been observed, that the sudden compression of any quantity of common air is attended with a great degree of heat, and its sudden expansion with a great degree of cold. Thus, if a piston, having a small piece of tinder attached to it, be pressed suddenly down in a cylinder of air or gas, the heat evolved, or squeezed out, by the compression will ignite the tinder; and again, if a delicate thermometer be placed under the receiver of an air-pump, it will indicate cold produced on every stroke of the pump. These effects will not continue long, since there will be an immediate transfer of heat, according to the well known laws of the radiation of heat; thus the heat evolved by the condensation will be rapidly lost among, and that absorbed by the expansion will be supplied from, the surrounding bodies, the general fact being, that the temperature always tends rapidly to equilibrium. The beautiful and simple apparatus of Gay-Lussac may be mentioned, since it exhibits at once both the phenomena in question. Let two spherical glass vessels communicate with each other by a stop-cock, and have a delicate thermometer suspended at their centres; then if one have the air exhausted, and the other be filled by a condenser, either with common air or with a gas, and the stop-cock be opened so that the condensed air rushes into the empty vessel, the thermometer in one vessel will sink and in the other will rise; namely, it will sink in that which is being emptied, or in which the air is expanding, and it will rise in that which is filling, or in which the air is being condensed; and when the experiment is

made with great care, it will be seen that the cold indicated by one corresponds exactly to the heat indicated by the other. If another thermometer be suspended in the empty vessel close by the orifice, that is, just where the air is in the act of expanding, a very great degree of cold will be indicated; and this will diminish rapidly as it is placed further from the orifice. These indications of heat and cold continue but for a very short period, since the equilibrium of temperature is almost instantaneously restored. No accurate measure of the heat absorbed and developed can be procured by direct observations on the thermometer; it may, however, be calculated from the change in the elastic force, as we shall see presently. This experiment of Gay-Lussac does not appear to have been repeated on a large scale; but I conceive that if a large cylinder of thin metal were placed in communication with a vessel of condensed air at a great pressure, the cold produced at the one end, where the expansion was proceeding, and the heat produced at the other, where the condensation was taking place, would be quite sensible to the hand, and a series of air-thermometers would indicate very different states of temperature at the same distances from each end. But the important practical inquiry is the change which this developement and absorption of heat produces on the elastic force of the fluid; there must be increase of elastic force due to this increase of temperature, and a diminution of elastic force due to the diminution of temperature, besides the increase and diminution which is due to the change of density according to Boyle's law. In fact, we know that Boyle's law is not true, unless the compressed air is allowed time to cool, as was distinctly ascertained in the series of experiments made by order of the Academy of Paris on this subject. In the complete investigation of it by Desormes and Clements, which I have detailed at full length in my Theory of Fluids, Article 98, the increment of temperature is calculated by a series of mathematical reasoning, from this very change in the elastic force for which I contend. The problem proposed was "to determine the increment of temperature for a given small condensation." They observed the successive changes which the mercurial column underwent when air was first let into an exhausted receiver, and after it had lost the small increase of temperature due to the small condensation. The column always sunk by a small quantity, and the amount of this change enabled them to determine the amount of heat developed for a given condensation. Of the accuracy of their results there cannot be the least doubt, for two other and quite independent phenomena, in which

the same causes are called into operation, namely, the production of sound and the vibration of a cylindrical column of air, give results according with very great accuracy. The preceding facts are mentioned, to give confidence in the principle for which I contend, that whenever there is a change in elastic force according to the law of Boyle due to the density, there is also an additional change in the elastic force due to the change of temperature, which is the necessary consequence of this change in the density: for it must be remembered, that in all the experiments, the elastic force agrees with the law of Boyle so soon as the equilibrium of temperature is restored.

On this part of the subject it is unnecessary to insist, since the facts are well established for most of the elastic fluids, but the experiments, so far as I have become acquainted with them, do not extend to steam, and unless there be some reason for excluding steam from the general properties of all other elastic fluids, we must admit the preceding conclusions with respect to it also. Now so far from having any reason to except steam from these laws, we have every reason for believing that steam separated from its water, and maintained at a higher temperature than 212°, differs in no respect from the permanent gases. It can be readily liquified, but doubtlessly all the gases can be reduced to the same form by a proper increase of pressure and diminution of temperature.

For if we consider steam as an elastic fluid owing its elastic qualities solely to the repulsive power of heat, there can be no reason *à priori* for excepting it from the laws of other elastic fluids, which appear to owe their energy and existence to the same cause. Now so far as experiments have been made, it appears that steam expands equally for all equal increments of temperature; thus following the law of other elastic fluids. There is a passage in Professor Robison's Treatise on Steam which involves the principle in question, but which appears not to have been followed out. He says, "it is "well known that when air is suddenly expanded, cold is produced, and heat "when it is suddenly compressed. When making experiments with the hopes "of discovering the connexion between the elasticity and density of the "vapours of boiling water and also of boiling spirits of turpentine, we found "the change of density accompanied by a change of temperature vastly greater "than in the case of incoercible gases. When the vapour of boiling water "was suddenly allowed to expand into five times its bulk, we observed the "depression of a large and sensible thermometer to be at least four or five

“ times greater than in a similar expansion of common air at the same tem-
“ perature.”

The fact of the depression being greater in the expansion of steam than of air at the same temperature, is explicable at once from the different constitutions of the two fluids with respect to the properties of heat; but on this I cannot at present enter. The fact is invaluable as coming from such a man, and, when viewed in connexion with the general theory of elastic fluids, and the above-mentioned law of Gay-Lussac respecting the expansion of steam for increments of temperature, entitles us to assume that, so long as steam retains its gaseous character, it is subject to the laws of gases. These conclusions might be sustained by many well known phenomena respecting vapours and evaporation generally, but enough has been said to warrant our including steam in the general law of the French philosophers respecting elastic fluids: “ That “ equal volumes of all elastic fluids, taken at the same temperature and the “ same pressure, being suddenly compressed or expanded by the same fraction “ of their volume, disengage or absorb the same absolute quantity of heat.”

Now the degree of heat or cold produced depends on the rate at which the change takes place; and this consideration will lead to some important conclusions with respect to the expansion of high-pressure steam. The rate of expansion will obviously depend on the elastic force of the steam; the higher pressure therefore which we use the greater will be the cold and the greater the diminution of the elastic force beyond that which the law of Boyle would give. Suppose steam of ten atmospheres suddenly to expand to four times its bulk, then the elastic force of the expanded steam ought, on these principles, to be much less than the elastic force of steam of five atmospheres suddenly expanded to twice its bulk; and the greater the elastic force of the steam, the greater will be the deviation from the law of Boyle. So that, while Boyle’s law will be nearly true for steam of one or two atmospheres, it will be most untrue for steam of five or ten atmospheres. These, I conceive, are results which may be readily tested by careful experiments. I know of none in which they have been fairly examined, for I am not willing to admit the conclusions which may be drawn from some accounts of steam worked expansively, and which would appear to militate against these principles; but on this I shall say more immediately.

It would appear then, that the mere rate of expansion may be such, that

the diminution of elastic force, consequent on the diminution of temperature, may leave scarcely any elastic force in the expanded steam; so that there may be extreme cases in which the law of Boyle will appear absolutely false. These conclusions appear to me supported and illustrated by the facts, that high pressure steam does not scald, and that elastic steam is not so efficacious as gunpowder for throwing bullets or other masses.

When low pressure steam expands into the air, it preserves very nearly both its density and its temperature, but when steam of a high pressure expands, the instantaneous augmentation of volume demands that a large portion of heat should become latent, or it cannot exist at all as steam. If the expansion were to stop the instant at which the elastic force of the steam becomes equal to that of the atmosphere, its temperature would (since the sum of the sensible and latent heat is invariable) descend only to 212°; but in consequence of the momentum which the particles have acquired from the rapidity of the expansion, it expands far beyond this limit, so that the diminution of temperature becomes greater, in proportion as its original elastic force was greater than the elastic force of the atmosphere. If this expansion takes place in a vacuum, the reduction of temperature will be greater still, since the particles of air present mechanical obstacles to the expansion. So that in some cases the elastic force may be lost almost entirely. We know, thanks to the ingenuity of Mr. Perkins, that highly elastic steam will impel bullets with considerable velocity; this velocity does not, however, appear to be equal to that which can be generated by gunpowder. Now in order to increase the velocity, we must increase the elastic force of the steam, the consequence of which being an increased rapidity of expansion, the additional reduction of temperature may more than nullify the original increase of elastic force, so that steam at a higher pressure will be less efficacious than steam of a less pressure. If this be the case, there is some temperature at which for a given ball the effect is a maximum, that is, greater than either at a higher or a lower temperature. But in the case of gunpowder the temperature of the elastic fluid is kept up by the continued consumption of fresh materials; the heat evolved during the combustion of these ingredients is quite prodigious, so that we have, in fact, the repulsive power of heat itself in full agency. I have said nothing respecting the density of the steam at different temperatures, my object not being to discuss this question fully, but merely to illustrate what must, I conceive, be the necessary consequence of increasing the temperature and elasticity of the steam beyond certain limits.

The application of these principles to the working of *steam expansively* is at once apparent; there will in every case be a diminution in the pressure exerted beyond what will be given by Boyle's law, and this will be greater the more rapidly the engine is worked. But on this subject I hardly dare venture any remarks; practical considerations are of much greater value than any which I can offer, especially as in one large class of engines, namely, in condensing engines, where the steam is worked at a low pressure, the deviations from the Boylean law, due to the cause which I have mentioned, cannot be considerable; still, however, these deviations must, I conceive, be appreciable whenever the steam is generated at a higher temperature than 212°. But in high pressure engines the deviations due to this cause must be considerable, and I would venture to suggest that if higher pressure steam be used than is from the circumstances of the case practically necessary, the steam generated is not applied in the most economical manner, so far as concerns the ratio of the work done to the fuel consumed. The preceding remarks have referred exclusively to steam separated from its water and maintained at such a temperature that it may be considered as a permanent gas. If the steam be not separated from its water, the case is so entirely different, that the preceding remarks do not at all apply.

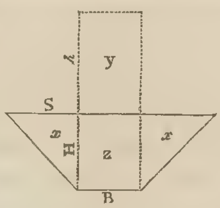
If the space above the water be not saturated with vapour, that is, if the vapour which it contains have not the maximum density due to the temperature of the water, it is owing to the mechanical obstruction of the particles of air; but since we suppose the air removed, or the space full of steam, we have to consider the nature of the changes which take place when this given space is increased or diminished, that is, when the pressure on the surface of the water is diminished or increased. In this case the law of Boyle has no existence, for it applies only to a permanent gas, that is, it is only a steam law, when the vapour is detached from its liquid and contained in a space of such a temperature that it may be considered as a permanent gas. The pressure of the existing vapour on the surface of the water being the only limit to the formation of fresh vapour, whenever the pressure on this surface is diminished in the boiler by the withdrawal of a portion of the steam, fresh steam will instantly be formed, so that if, where steam is worked expansively, there be any water at the bottom of the cylinder, or any communication whatever with any water, the effect will be precisely the same as if the communication with the boiler were not entirely cut off; there will be a constant accession of steam, or fresh steam will be formed as fast as

the piston rises. It has sometimes been stated that where steam is worked expansively, the effect is greater than the Boylean law would lead us to suppose; if such appear to be the case, it must be from some such cause as the above mentioned; either the steam is not entirely cut off, or there is some communication with water: the smallest quantity of water will be sufficient to increase very considerably the apparent effect, and cause a great deviation from the calculated elastic force. The whole theory of this subject is so intimately connected with the theory of heat, and the elasticity of the fluid depends so entirely on the repulsive power of heat, that the consequence of its known laws may be immediately traced in every application of steam; hence we may be convinced that there is a loss of elastic force, besides that which is due to the change in density, whenever steam is worked expansively, however much it may be practically overruled and modified. As a means of detecting this I would mention, that it ought to be shewn by the greater supply of heat which a cylinder requires when the steam is worked more expansively, than where the same steam is worked less expansively. From these considerations we may see that there is a maximum in the useful effect of expansion working; but the complete determination of it is a purely practical question, and since it will depend on the conducting power of the metal, it must be somewhat different for every different engine.

XXVI. *A method of representing by diagram and estimating the earthwork in Excavations and Embankments.* *By* John James Waterston, *A.Inst. C.E.*

The object of this paper is to describe the construction of two sets of scales, by the use of one of which a section may be plotted, representing the actual amount of material contained in any cutting or embankment, of the relation of which to each other a mere profile of the country, from not showing the contents of the side slopes, gives but an imperfect idea, even to professional men, particularly if the heights and depths be at all considerable, or if the slopes be not uniform; and by the other a computation of the quantities may be made, almost by the arithmetical process of addition only.

The principle on which the first operation is effected, is to accumulate the contents of the slopes x, x, into the rectangle y, over the middle part z in cutting, and under it in embanking, which is done by the formula $h = \frac{r}{B} H^2$, wherein B denotes the base or width of the excavation or embankment, as the case may be, H its depth, r the ratio of the slope, or of S to H, and h the height of the rectangle y, substituted in lieu of the slopes x, x. From this theorem, the scale shown on the drawing (plate no. XXIV, fig. 1) is constructed, the heights H being marked on the vertical line m, and the supplemental heights h on the lines n, n, at right angles to it; and if a curve be drawn through the extremities of the latter lines, it will, as is evident from the equation, be a true parabola.



The scale thus constructed is used as follows. The axis being laid over the line of the railway, one leg of the dividers is placed at the point where the perpendicular line m is intersected by the surface of the ground, and the horizontal distance to the curve being taken in the compasses, is set off vertically over the point of intersection. The scale is then moved along, the axis coinciding with the surface of the railway*, which is easily done in

* Strictly, the line m should be *vertical*, but, except where the heights and depths are great or

practice by running it on a straight edge, as shown on the plan, and the operation is repeated until a sufficient number of offsets being obtained, the line of section *abcd* is drawn through them, and may be considered supplemental to the actual section of the ground *ABCD*, the superficies included between them representing what is due to the *slopes*, and that between the latter and the line of the railway what is due to the *middle*, while the product of the whole area, multiplied by the base or width of roadway, gives the total cubical content of the cutting or embankment. But the scale to be described presently, is better adapted for reducing the quantities to *figures*, the above being intended more to exhibit to the *eye* the true amounts of excavation and embankment, which, it is conceived, may be useful, especially in parliamentary investigations, in which the engineering evidence so frequently turns on such points.

In applying the scale to the case of canals, the process will be the same as in the foregoing, which has been described as for railways and roads, except that the line of supplementary profile, instead of being referred to the line denoting the surface of the banks, must be plotted from a parallel line drawn below it, at a distance equal to the transverse area of the water channel divided by the width or base at that surface; and, indeed, in the cuttings for railways this will also have to be done to an extent, to allow for the ballasting. And with respect to an objection that may be taken to the number of the proposed scales it will be necessary to possess, in consequence of every combination of *original* vertical scale with width of base requiring one of them peculiar to itself, I would remark that though no doubt this is the case *, practically there is no very great variety in the scales commonly used by engineers and surveyors, or at all events the same individual generally adopts the same scales for the same purposes.

the inclinations steep, the error from holding it perpendicular to the gradient is not of practical importance.

* If only the parabolic curve, and the tangential line m at its apex, be marked permanently on the scales, and the perpendiculars n, n, be traced on it as the occasion requires, one scale will be enough for every purpose, the division of the tangent m (by which, and the curve, the lines n, n are also determined) being effected by the use of the formula $H' = H\sqrt{\frac{lr}{B}}$, in which H, r and B, are the same as in the text, l is the latus-rectum of the parabola, and H' the point in the new graduation to be substituted for H in the original division; and one point being thus gained, all the others of course follow by equidistances. When the latus-rectum is large, the parabola is more obtuse, and the lines n, n, better defined.

The scale shown on fig. 2 was suggested by my ingenious friend Mr. Henry E. Scott, to whom it occurred as a modification of the above, which I had described to him. It is exceedingly simple, and the mode of using it almost self-evident. The ordinary section has only to be divided into equal lengths of say a chain, and the scale being applied to it at each point of division, with zero on the base line, the cubic quantity contained in that length on the given width and slopes is read off at the intersection with the surface of the ground; after which the content of the whole cutting or embankment is obtained by simply adding those figures together. The degree of accuracy that will be afforded must of course depend on the minuteness of the graduation, as all measurements with scales do; and if it appears impossible to go to *feet and inches* by this one, unless the section be very large, it should be borne in mind that the result given is final, and that (to say nothing of the liability to error in casting) any portion of inaccuracy that may be in it is not subject to increase by multiplication, which, if considered, may be found to affect to as great an extent quantities calculated from the *primary* dimensions.

The construction of the scale is derived from the easily investigated formula $H=\sqrt{\frac{B^2}{4r^2}+\frac{9A}{r}}-\frac{B}{2r}$, in which A is the transverse area in square yards, the other letters expressing the same elements as before; or if Q denote the cubic content in yards, the equation $H=\sqrt{\frac{B^2}{4r^2}+\frac{9Q}{22r}}-\frac{B}{2r}$ is adapted for calculating the quantities in lengths of a chain each. This will give the total content, but as, when estimates are in progress, the angle the ground will stand at may not have been precisely ascertained, and perhaps have to be corrected afterwards, it is sometimes desirable to keep the slopes separate for a time from the middle or rectangular part, in which case the scale may be conveniently graduated on the one edge for the middle portion by $H=Q\frac{9}{22B}$, and on the other, for the slopes, by $H=\sqrt{\frac{9Q}{22r}}$. The following table has been constructed by way of specimen from these formulæ, and shows the heights which, measured on the scales, give the points corresponding with the cubic quantities in the first column, the length in all cases being taken as one chain, the width or base as thirty feet, and the slopes as stated; but the quantities for other lengths, widths, and slopes are, as I need hardly say, in the simple proportion of the variation in any one of the dimensions.

Q = number of cubic yards.	I. MIDDLE AND SLOPES TOGETHER. $H=\sqrt{\frac{B^2}{4r^2}+\frac{9Q}{22r}}-\frac{B}{2r}$				II. MIDDLE WITHOUT SLOPES. $H=Q\frac{9}{22B}$	III. SLOPES WITHOUT MIDDLE. $H=\sqrt{\frac{9Q}{22r}}$			
	$r =$					$r =$			
	$\frac{1}{2}$	1	$1\frac{1}{2}$	2		$\frac{1}{2}$	1	$1\frac{1}{2}$	2
	H Feet.	H Feet.	H Feet.	H Feet.	H Feet.	H Feet.	H Feet.	H Feet.	H Feet.
250	3.2	3.1	3.0	2.8	3.4	14.3	10.1	8.2	7.1
500	6.2	5.7	5.4	4.8	6.8	20.2	14.3	11.6	10.1
750	9.0	8.1	7.5	6.8	10.2	24.8	17.5	14.3	12.4
1000	11.4	10.2	9.3	8.6	13.6	28.6	20.2	16.5	14.3
1500	16.1	13.9	12.5	11.5	20.4	35.0	24.8	20.2	17.5
2000	20.4	17.3	15.4	14.1	27.3	40.5	28.6	23.3	20.2
2500	24.3	20.3	18.0	16.3	34.1	45.2	32.0	26.1	22.7
3000	27.9	23.1	20.3	18.4	40.9	49.6	35.0	28.6	24.8
4000	34.6	28 1	24.5	22.1	54.5	57.2	40.5	33.0	28.6
5000	40.7	32.6	28.2	25.3	68.2	64.0	45.2	36.9	32.0
6000	46.2	36.8	31.7	28.3			49.6	40.4	35.0
7000	51.4	40.3	34.8	31.1			53.5	43.7	37.9
8000	56.3	44.1	37.8	33.6			57.2	46.7	40.5
9000	60.9	47.5	40.5	36.1			60.6	49.6	42.9
10,000	65.3	50.7	43.2	38.3			64.0	52.2	45.2
11,000		53.7	45.6	40.5				54.8	47.3
12,000		56.6	47.9	42.6				57.2	49.6
13,000		59.3	50.3	44.6				59.7	51.4
14,000		62.0	52.5	46.5				61.9	53.5
15,000		64.7	54.7	48.4				64.0	55.4
16,000			56.7	50.2					57.3
17,000			58.7	52.0					59.1
18,000			60.7	53.7					60.8
19,000			62.6	55.3					62.4
20,000			64.5	56.9					64.0
21,000				58.5					
22,000				60.1					
23,000				61.6					
24,000				63.0					
25,000				64.4					

XXVII. *Remarks on Herm Granite, by* FREDERICK C. LUKIS, *Esq., of Guernsey, in reply to enquiries from the President; with some Experiments made by the latter on the wear of different granites. Communicated by the President.*

Also, Experiments on the force required to fracture and crush stones; made under the direction of Messrs. BRAMAH *and* SONS, *for* B. WYATT, *Esq., Architect. Communicated by Mr.* WILLIAM FREEMAN, *A.Inst.C.E.*

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1. Of the durability of Herm stone for buildings exposed to air?

THE Herm granite (sienite) as compared with Peterhead and Moorstone from Devon or Cornwall, is a highly crystallized intermixture of felspar, quartz, and hornblende, with a small quantity of black mica; the first of these ingredients hard and sometimes transparent in a greater degree than that found in other British granites,—the contact of the other substances perfect. It resists the effect of exposure to air, and does not easily disintegrate from the mass when mica does not prevail, but as this last is usually scarce in Guernsey granites, the mass is not deteriorated by its presence as in the Brittany granites, where it abounds, decomposes, stains, and pervades the felspar, and finally destroys the adhesion of the component parts:—*vide* the interior columns of St. Peter's Port church, which is built of it, for an instance. The quartz is in a smaller quantity, and somewhat darker than the felspar in colour; the grains are not large, but uniformly mixed with the other ingredients. The hornblende, which appears to supply the place of mica, is hard and crystallized in small prisms, rarely accompanied by chlorite; its dark colour gives the greyish tone to this granite, or when abundant forms the *blue* granite of the Vale parish. This substance is essentially superior to mica in the formation and durability of granites for strength and resistance; consequently its presence occasions more labour in working or facing the block, and its specific gravity is increased. The mica is inferior in quantity to the hornblende, and usually dispersed in small flakes in the mass;—it may, with chlorite, be considered rare.

2. Do air and water alternately cause any, and what symptoms of decay?

The compact nature of a close grained granite, such as the Vale and Herm stone, having the felspar highly crystallized and free from stained cracks, seems well calculated to resist the effect of air and water. When the exterior *bruised* surface of a block has been blown off, I do not know a stone better disposed to resist decay;—if the surface blocks of the island are now examined after the lapse of ages, it will be found to have resisted the gradual disintegration of time in a superior degree, when compared with *large grained* or *porphyritic* granite; when exposed to water and air there is no change beyond the polish resulting from *friction* of the elements. Among the symptoms of decay, disintegration prevails generally among granites, usually commencing with the decomposition of the mica; its exfoliating deranges the cohesion of the grains, and it may be considered then to be the more frequent mode of decay. Desquamation is rare with the well defined granites of Guernsey and Herm, and in buildings I know no instance of its existence.

3. What the greatest age of building, or experience of the above?

The churches of the Vale and St. Sampson, although much of the materials are French and Alderney, bear many proofs of the remarks made in the last answer; these erections date A.D. 1100—1150. The ancient buildings of decided Herm and Vale stone must be sought for among the old houses in the northern parishes, where they not only encounter the effect of air and water (rain), but the sea air and burning rays of the sun. Disintegration alone appears going on by slow degrees, but in no case affecting the interior of the stone, and so gradual and general as not to deface the building materially; indeed, the oldest proofs taken from door-posts, lintels, and arches, have scarcely lost their original sharpness or sculpture. The pier of St. Peter's Port and bridge of St. Sampson's may also be mentioned.

The shore rocks in like manner do not show any material change of surface by wearing; where the force of the tide is strongest, a slight smoothness alone may be observed on the exterior particles, and in many instances each substance possesses this polish *without being levelled down to a face.*

Vale stone on the northern point of Guernsey produces a finer grained sienite than Herm, more hornblende in it, and specific gravity greater. The Herm is somewhat larger grained, but equally good for every erection where durability is the chief point. The *Cat-au-roque* stone in the western part of Guernsey must be considered of a different structure to the above: it is a fair and good stone and appears to last well; its schistose texture must ally it to the gneiss series, and I do not know its counterpart in Britain. In colour it is much the same as the blue granites, the felspar is brilliant and the hornblende prisms are well defined; there is more chlorite in it and it is easier to work.

Table shewing the result of experiments made under the direction of Mr. W*ALKER*, *on the wear of different stones in the tramway on the Commercial Road, London, from 27th March,* 1830, *to 24th August,* 1831, *being a period of seventeen months.*

Name of stone.	Sup. area in feet.	Original weight.			Loss of weight by wear.	Loss per sup. foot.	Relative losses.
		cwt.	qrs.	lbs.	lbs.	lbs.	
Guernsey	4.734	7	1	12.75	4.50	0.951	1.000
Herm	5.250	7	3	24.25	5.50	1.048	1.102
Budle	6.336	9	0	15.75	7.75	1.223	1.286
Peterhead (blue)	3.484	4	1	7.50	6.25	1.795	1.887
Heytor	4.313	6	0	15.25	8.25	1.915	2.014
Aberdeen (red) .	5.375	7	2	11.50	11.50	2.139	2.249
Dartmoor	4.500	6	2	25.00	12.50	2.778	2.921
Aberdeen (blue)	4.823	6	2	16.00	14.75	3.058	3.216

The Commercial Road stoneway, on which these experiments were made, consists of two parallel lines of rectangular tramstones, 18 inches wide by a foot deep, and jointed to each other endwise, for the wheels to travel

on, with a common street pavement between for the horses. The tram-stones subjected to experiment were laid in the gateway of the Limehouse turnpike, so as of necessity to be exposed to all the heavy traffic *from* the East and West India Docks. A similar set of experiments had previously been made in the same place, but for a shorter period, (little more than four months,) with however not very different results, as the following figures corresponding with the column of "*relative losses*" in the foregoing table will show.

Guernsey	1.000	Peterhead (blue) . .	1.715
Budle	1.040	Aberdeen (red) . . .	2.413
Herm	1.156	Aberdeen (blue) . .	2.821

All the above stones are granites except the Budle, which is a species of whin from Northumberland, and they were all new pieces in each series of experiments.

Experiments made with Messrs. Joseph Bramah and Sons' hydro-mechanical press on various specimens of stone.

The following experiments were made with a 12 inch press, the pump one inch diameter, and the lever 10 to 1;—the mechanical advantage therefore $144 \times 10 = 1440$ to 1. The weights on the lever were added by 7 lbs at a time;—each addition therefore equivalent to $1440 \times 7 = 10,080$ lbs or $4\frac{1}{2}$ tons.

In consequence of the smallness of the specimens, the press was filled with blocks to the required height, and with these the surplus effect of the lever was $4\frac{1}{2}$ lbs at 10 to 1, which strictly should be added to the pressure, but as the friction of the apparatus is equal to the effect of the lever, it is dispensed with in the calculation.

The column containing the pressure per square inch required to produce a fracture, gives the true value of the stone, as the weight that does so would possibly completely destroy the stone if allowed to remain on for a length of time. It should also be observed, that from the exceedingly short time allowed for the experiments, the results are probably too high.

TABLE OF EXPERIMENTS.

Description of Stone		Weight of each specimen.		Dimensions.	Surface exposed to pressure.	Pressure required to fracture stone.			Pressure required to crush stone.		
						Total to each specimen.	Per sup. inch of surface.	Average per sup. inch.	Total to each specimen.	Per sup. inch of surface.	Average per sup. inch.
		lbs.	oz.	Lineal Inches.	Sup. Ins.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Granites...	Herm	6	6	$4 \times 4 \times 4$	16	80.0	5.00	4.77	116.0	7.25	6.64
		6	6	$4 \times 4 \times 4$	16	72.5	4.53		96.4	6.03	
	Aberdeen (blue)	5	0	$4 \times 4\frac{1}{4} \times 3$	17	81.0	4.76	4.13	85.5	5.03	4.64
		5	$1\frac{1}{2}$	$4 \times 4\frac{1}{2}$ 3	18	63.0	3.50		76.5	4.25	
	Heytor	4	7	$4 \times 4 \times 3$	16	67.5	4.22	3.94	103.5	6.47	6.19
		4	8	$4 \times 4 \times 3$	16	58.5	3.66		94.5	5.91	
	Dartmoor	4	10	$4 \times 4 \times 3$	16	67.5	4.22	3.52	103.5	6.47	5.48
		4	8	$4 \times 4 \times 3$	16	45.0	2.81		72.0	4.50	
	Peterhead (red)	5	5	$4\frac{1}{2} \times 4 \times 3\frac{1}{8}$	18	58.5	3.25	2.88	94.5	5.25	4.88
		4	12	$4\frac{1}{2} \times 4 \times 3$	18	45.0	2.50		81.0	4.50	
	Peterhead (blue-grey)	5	$3\frac{1}{2}$	$4\frac{1}{2} \times 4\frac{1}{8} \times 3\frac{1}{8}$	18.6	58.5	3.14	2.86	85.5	4.60	4.36
		5	4	$4\frac{1}{2} \times 3\frac{7}{8} \times 3\frac{1}{8}$	17.5	45.0	2.57		72.0	4.11	
	Penryn	5	7	$4\frac{5}{8} \times 4 \times 3$	18.5	63.0	3.41	2.58	72.0	3.90	3.45
		5	4	$4\frac{1}{2} \times 4 \times 3\frac{1}{8}$	18	31.5	1.75		54.0	3.00	
Marbles...	Ravaccioni	5	10	$4\frac{1}{2} \times 4 \times 3\frac{1}{8}$	18	78.5	4.35	3.55	83.0	4.61	4.30
		5	9	$4\frac{1}{2} \times 4 \times 3$	18	49.5	2.75		72.0	4.00	
	Veined	5	6	$4\frac{1}{2} \times 4 \times 3$	18	45.0	2.50	2.12	85.5	4.75	4.13
		5	9	$4\frac{1}{2} \times 4 \times 3$	18	31.5	1.75		63.0	3.50	
Gritstones.	Yorkshire (Cromwell-bottom)	12	8	$5\frac{1}{2} \times 5 \times 5\frac{1}{8}$	27.5	81.0	2.95	2.87	121.5	4.42	3.94
		12	5	$5\frac{1}{2} \times 5 \times 5\frac{1}{8}$	27.5	76.5	2.78		95.5	3.47	
	Craigleith	11	10	$5 \times 5 \times 5\frac{1}{2}$	25	63.0	2.52	1.89	85.5	3.42	2.97
		11	6	$5 \times 5 \times 5\frac{1}{2}$	25	31.5	1.26		63.0	2.52	
	Humbie	17	10	$6 \times 6 \times 6$	36	72.0	2.00	1.69	81.0	2.25	2.06
		17	3	$6 \times 6 \times 6$	36	49.5	1.37		67.5	1.87	
	Whitby	16	10	$6 \times 6 \times 6$	36	36.0	1.00	1.00	40.5	1.12	1.06
		15	12	$6 \times 6 \times 6$	36	36.0	1.00		36.0	1.00	
Valentia slate* (laminæ vertical)		....		$3 \times 3 \times 3$	9	30.4	3.38	3.38	47.6	5.29	5.29

* A few experiments were also made with inch cubes of this slate, placed on their natural bed, the results of which were 5.44 and 4.83 tons respectively, or, on the average, 5.14 tons per square inch of exposed surface, to crush the stone. A trial on a similar small cube with the laminæ vertical, gave 5.98 tons as the corresponding result. The specific gravity of Valentia slate appears to coincide very nearly with that given by Kirwan for Welsh slate.

XXVIII. *Recent* Canal-boat Experiments.—Description and Tabulated Results of a Series of Experiments made to ascertain the actual Tractive Power exerted in drawing Boats on Canals, under various circumstances of Load, Speed, &c.* By John Macneill, *Esq., M.I.C.E., F.R.A.S., M.R.I.A.*

The series of Tables which I now have the honour of presenting to the Institution, have no merit beyond that of an honest and accurate Register of Facts. That the Experiments which they record were made neither to support nor to invalidate any theory, the following account of their origin will demonstrate.

The attention of the Committee of Management of the Forth and Clyde Canal Company, had frequently, in the course of their extensive and varied experience, been directed to some results, in the use of boats of different forms, on different canals, which appeared to contradict notions considered to be long established. The paradoxical character and important consequences of these results, at length determined the Committee, that a careful examination of the circumstances under which they had been observed should be made, and that upon a scale which should be free from the usual objections attending experiments made with models. I had the honour of receiving their commands to design and conduct this inquiry. In July, last year, I carried the examination into effect, with the boats, and on the canals, which had apparently presented the anomalous facts. The object aimed at, and which was supposed would satisfactorily settle every question, was to ascertain the tractive power exerted in drawing these boats on the canals in question, under very various circumstances of load, speed, &c. At least, one beneficial result seemed certain to be attained by the parties who had the spirit to undertake the inquiry, in consequence of their being interested in the navigation of the canals, viz.—it would determine which of the boats in use was best adapted for the purpose for which it was intended.

* This term is preserved to distinguish these Experiments from others of the same kind, which Mr. Macneill had previously made on the Grand Junction Canal, &c.

Though thus somewhat restricted by the very object of the inquiry, I could not help hoping, that a vigilant attention to all the circumstances attending the numerous and varied experiments which would be necessary to solve the problem, and a faithful register of every influential fact, might add some authentic data to the very small stock, hitherto collected from actual experiment, on this most important and interesting, but intricate, subject of physical science.

It is in this way that, I conceive, the practical engineer may frequently assist the physico-mathematician, and enable the latter to investigate and reduce to simple laws many of those apparent anomalies which often puzzle, and sometimes disappoint, the former. As neither my professional engagements, nor my acquirements, will permit me in any case to attempt mathematical discussions of this high and important character, I have aimed at no other distinction than that of a careful observer, and a faithful reporter of facts. This is the utmost of my pretensions in the present Paper, and so far as this, I must acknowledge, I am ambitious to establish a claim.

Canals.—The canals on which the experiments, which it is the object of this Paper to record, were made, are, viz.—the Forth and Clyde Canal, the Monkland Canal, and the Paisley (*Glasgow and Paisley*) Canal. These were measured in several places. Sections made out from these measurements are given in Plate 28, and they show, that each canal differs very materially from either of the others. These peculiarities should constantly be borne in mind in comparing and reasoning upon the experiments.

Courses.—The portions of the canals selected for the sites of the experiments in Tables I.—X. were straight, and as nearly uniform in breadth and depth as could be obtained. These sites are designated, for distinction, the *courses.* On the Forth and Clyde Canal, there was no difficulty in the choice of a proper course of any desirable length. On the Monkland and on the Paisley Canals, no long line, free from objection, could be obtained; and, therefore, the courses on them were necessarily shorter.

Courses on the Forth and Clyde Canal.—Six stakes, marked a, b, c, d, e, f, were driven into the bank of the canal at intervals of 110 yards$=\frac{1}{16}$ of a mile. The first stake-interval a-b was used for getting the horses into the proper speed, and the boat into a uniform velocity, it is therefore not regarded in the Tables. The instants of the boat's passage of the stakes b, c, d, e, f, were accurately observed. These are given exactly as they stand

in the minute-books of the recorders, in column C of the Tables. From these epochs the times of the passage of the boat through the stake-intervals, or *runs*, *b-c*, *c-d*, *d-e* and *e-f*, were obtained by simple subtraction. These times are given in column E. The velocity in *miles per hour* and *feet per second* were then calculated from the preceding data, and the results are given in the columns F and H. In the experiment given in Table XII., the run extended about eight miles, but in this the tractive power only was observed.

Courses on the Monkland and Paisley Canals.—From reasons already stated, the courses on these canals were necessarily short. They had but three stake-intervals, and consequently only two runs. In every other respect they were the same as the course on the Forth and Clyde Canal. In the experiment given in Table XI., the run extended along the whole canal, and was about eight miles in length; but in this, as in the similar long run on the Forth and Clyde, the tractive power only was observed.

Boats.—All the boats had been, or were, in actual use on the canals in question, except one which had never been tried before, which is called "New Boat," to distinguish it. Plans, &c. of the most remarkable boats are given in Plate 27. Their weights will be found in column P of the Tables.

The loads and speeds of the boats were varied so as to include every case that had occurred, or was likely to occur, in practice. The speeds or velocities are given in columns F and H, and the loads in column J. The effects of the various loads, and of the different distributions of them, upon the draught of the boats, are given in columns L and M.

Instruments, and Manner of using them.—The *Dynamometer*, or instrument for ascertaining the tractive power exerted, was made a part of the connexion of the towing-line with the boat, so that all efforts to draw the boat by pulling the towing-line acted upon the instrument, and were indicated by it. Efforts from 1lb. up to nearly 600lbs. were clearly indicated on a large dial-plate, and could be satisfactorily read off.*

* This instrument was similar to one I had previously designed and caused to be constructed, for ascertaining the amount of the draught of carriages drawn by horses on turnpike-roads. The principle is the same as that used in the spring-weighing machine, but the index of this

The times of the runs were observed with chronometers in the following manner:—An assistant was so placed on the outside of the boat, that he could accurately observe the moment of passing a stake. When this happened, he called out, and the instant was observed and registered by two assistants, each with a separate chronometer. These time-observers were found, on comparing their registers, never to have differed more than half a second from each other, and that in a very few instances only. The tractive power was obtained by three assistants: one gave a signal every two seconds; another, on this signal, read off aloud the figures at which the index pointed; and a third registered. By this arrangement all hurry and confusion were avoided; each assistant had ample time to do the work allotted to him; and it is believed, that few errors, and none of any magnitude, occurred in making or noting the observations. The numbers representing the tractive power were written down in columns, each column corresponding to a run, or stake-interval. The sum of a column divided by the number of observations, gave a number which was considered to be the mean tractive power in lbs. exerted during each run. These calculations were afterwards checked by two other persons.

In many of the experiments the level of a theodolite, steadily fixed in the boat, was observed under the following circumstances:—The boat, with its load distributed for the experiment, being at rest, the bubble was brought to the middle of the tube, and the index set at zero. The bubble being preserved in the same place during the experiment, the angle read off on the limb gave the angle of variation, which the keel of the boat made with its

instrument in its simple form, when applied to measure horse-draught, vibrates too frequently, and over too large an arc, for correct observation. This is a consequence of the peculiar nature of horse-draught, which is not a uniform pull, as is popularly supposed, but a succession of impulses or strokes of the animal's shoulder against the collar. I added an apparatus, which indicated the mean force of the pulls, and not only reduced the vibrations of the index, but, like the fusee of a watch, compensated for the increasing resistance of the spring in high efforts. A detailed description of this Road-Dynamometer, and its application on the whole length of road from London to Holyhead, is given in *the Seventh Report of the Parliamentary Commissioners for Maintaining the Road from London to Holyhead.* The instrument is also described in the *Further Report made by the Commissioners appointed to Inquire into the Post-Office Department, on the Subject of the Mail Coaches, dated* 13*th Aug.* 1835. The instrument used on the canals was made from my designs, by Messrs. Bramah, of Pimlico, and was most carefully and beautifully finished.

position before starting, or the difference, if any, between a state of rest and one of motion. Many of the angles observed are given in column O.

For the purpose of ascertaining if the boat was raised in the water, a fine wire was stretched across the canal, over two pullies placed in posts erected on the banks, by heavy weights attached to the end of it, so that it was very nearly level across the canal, and about eight inches higher than the boat. A bit of paper upon it marked the middle of the canal. On the top of the boat four slips of thin wood were placed,—one near the bow, one near the stern, and the other two at equal distances between them. These slips of wood were suspended vertically on fine wire pivots a little above their centre, so that they hung upright, except when they came in contact with the wire stretched across the canal; the moment they did so, they gave way, inclined backwards, and allowed the boat to pass freely under the wire: the edges of these slips were hollowed out, and the groove filled with tallow, projecting a little before the edge of the slip. The slips were divided into inches and tenths. When the boat was prepared and ready for an experiment, it was brought under the wire, and, being steadied near the paper-mark, the division cut by the wire on each slip was noted down. When the boat in motion passed under the same point, the wire struck the slips in succession, and stripped off all the tallow above a certain point with a sharp and clean cut, so that it was perfectly easy to determine the height to which the boat rose when in motion, by examining the slips, and comparing the divisions at which the tallow terminated with those previously noted.

Weather.—The weather was, almost without exception, extremely favourable for the purpose. The direction of the wind, its force, &c., are noted in column K.

Tables.—Such parts of the experiments as would admit of it, are classed together and tabulated to facilitate reference and comparison. Most of the columns have been described in the preceding paragraphs—the others require no explanation. The Tables I.—X. contain the experiments made on the courses. Tables XI. and XII. are the two eight-mile runs. In these the tractive power, indicated by the dynamometer, was read off as quick as it could be written down.

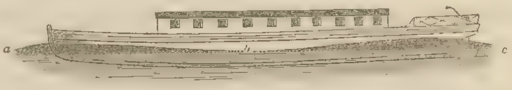
OBSERVATIONS.

1. That in the wide and deep canal, the tractive power was observed to increase with the velocity, but not in any uniform ratio.

2. That in the shallow and narrow canals, the increase of tractive power had a limit at a certain velocity; and, under certain circumstances, even decreased with the increase of velocity; so that it appears probable, that if the size of the canal bear a certain proportion to that of the boat, there is a certain velocity at which a boat may be drawn on a canal with a minimum tractive power. This velocity, on the Monkland and Paisley Canals, with boats like the Zephyr and the Swift, appears to be about nine miles per hour. And I think it probable that a similar effect would be observed on the Forth and Clyde Canal, if a boat similarly proportioned to that canal were used, though the velocity and the minimum tractive power in such a case might be different from those on the other canals.

3. That, in the long run on the Forth and Clyde Canal, the surface of the water regarded on the side of the boat, when in motion, was concave or hollow about the middle of the length of the boat, rising at the bow and quarter, as is shown by the line *a b c*, in Fig. 1.

Fig. 1.



4. That, in the long run on the Paisley Canal, precisely the opposite effect took place, the surface of the water about the middle of the length of the boat being convex, and higher there than at the bow and quarter, as *d e f*, in Fig. 2.

Fig. 2.

5. That there appears a relation between the tractive power and the horizontal position of the keel, the tractive power, it will be observed, diminishing and increasing in some ratio or other, as the angle of variation is smaller or larger.

6. That the boat absolutely rises during its motion. This fact was most satisfactorily demonstrated by the apparatus designed for the purpose. In some of the experiments, the mean of the several rises indicated by the four slips, was about four inches, the bow being, in every case, more elevated than the middle and stern. As this phenomenon is of recent observation, and as the persons who have observed and announced it have been held up to unmerited ridicule, I beg leave to conclude with an extract from a paper read before the Philosophical Society of Cam-

bridge, and published in their Transactions. The article is by one of the most profound physico-mathematicians in Great Britain, probably in the world, the Rev. James Challis, late Fellow of Trinity College,* Cambridge. The article is entitled, *Researches in the Theory of the Motion of Fluids.* Mr. Challis prefaces his Paper thus :—

"The subjects treated of in this communication are of a miscellaneous character, referring to several points of the theory of fluid motion, respecting which the author conceived he had something new to advance. In illustration of the principles he has attempted to establish, solutions are given of two problems of considerable interest :—the resistance to the motion of a ball-pendulum ; and, the resistance of the motion of a body partly immersed in water and drawn along at the surface in the horizontal direction. The principal object in the solution of the latter problem is, to account for the rising of the body in the vertical direction on increasing the velocity of draught, which, in some recent experiments on Canal Navigation, has been observed to take place."

After an elaborate investigation of the law of this phenomenon, and showing that it must follow from the principles established by the Author in the preceding part of the Paper, he concludes by observing, that,

"To obtain a numerical result respecting the rise of the body corresponding to a given velocity, we will suppose, for the sake of simplicity of calculation, that when the vessel is at rest, the centres of the spherical ends, and consequently the axis of the cylindrical part, are in the plane of the horizontal surface of the water. This circumstance may be produced by *loading* the upper part of the body without altering its specific gravity. Let $l =$ the length of the axis of the cylindrical portion ; then the area of the horizontal section of the vessel, at the level of the water surface, is $l\text{D} + \frac{\pi \text{D}^2}{4} - \frac{\text{D}^2}{2}$, its breadth being D. Now $\text{W} - w$ must be equal to the difference of the quantities of fluid displaced in the states of rest and motion, and is therefore equal to $\gamma g \left(l\text{D} + \frac{\pi\text{D}^2}{4} - \frac{\text{D}^2}{2}\right)$, γ being small. Therefore neglecting powers of $\frac{\gamma}{a}$ above the first,

* This gentleman has since succeeded to the Plumian Professorship of Astronomy, in the University of Cambridge, vacant by the appointment of Professor Airy as Astronomer-royal.

$$\left(l\mathrm{D} + \frac{\pi \mathrm{D}^2}{4} - \frac{\mathrm{D}^2}{2}\right)\gamma g = \frac{\mathrm{V}^2\mathrm{D}^2}{8}\left(2 - \frac{\pi}{4}\right).$$

Let $\frac{l}{\mathrm{D}} = 3$. It will then be found that $\mathrm{V}^2 = 696 \text{ ft.} \times \gamma$. And if $\gamma =$ one inch, or $\frac{1}{12}$, this equation gives $\mathrm{V} = 5{\cdot}19$ miles per hour; consequently, if $\mathrm{V} = 10{\cdot}4$ miles per hour, $\gamma = 4$ inches.

In general, neglecting $\frac{\gamma^2}{a^2}$, &c.

$$\mathrm{W} - w = \frac{\mathrm{V}^2 a^2}{2}\left(\sin\theta\cos\theta\,(2\sin^2\theta + 1) - \frac{\theta}{2}\right),$$

$$\text{Also, } \mathrm{W} - w = \gamma g\left\{l\mathrm{D} + \frac{\mathrm{D}^2}{2\sin^2\theta}(\theta - \sin\theta\cos\theta)\right\} \text{ nearly;}$$

therefore, as $\mathrm{D} = 2a\sin\theta$, it will be found that

$$\gamma = \frac{\mathrm{V}^2}{4g}\cdot\frac{\sin 2\theta\,(2\sin^2\theta + 1) - \theta}{4m\sin^2\theta - \sin 2\theta + 2\theta}, \; m \text{ being put for } \frac{l}{\mathrm{D}}.$$

If θ be assumed equal to 15°, and $m = 3$, this equation gives $\mathrm{V} = 7{\cdot}35$ miles per hour when $\gamma = 4$ inches."

"These results, which probably are but very rough approximations to matters of fact, may yet suffice to show, that when vessels and boats of the usual forms sail in the open sea, they may be expected to rise in some degree upon an increase of their velocity, and so much the more as they are less adapted to *cleave* the water. Our theory shows that the rise is the same for bodies of the same shape and proportions, moving with the same velocity, whatever be their absolute magnitudes; also, that this effect is equally due to the pressures on the front and stern of the vessel. The theory, in fact, determines these pressures to be in every respect alike; so that if we proceeded to investigate the total pressure in the horizontal direction, we should find it to be nothing when the motion is uniform. This may serve to show, that, if friction be left out of consideration, a front ill adapted to cleave the water is not unfavourable to speedy motion, if the stern be of the same shape; and that the resistance to the motion of vessels in the open sea is principally owing to the friction of the water against their surface. This cause operates to produce unequal actions on the front and stern, making the directions of the motions of the particles in contact with the surface of the former *less* inclined to the horizon than they would be in the case of no friction, and of those in contact with the surface of the latter *more* inclined. To counteract this inequality, probably the stern should be less curved than the front."

JOHN MACNEILL.

December, 1835.

RECENT

CANAL-BOAT EXPERIMENTS.

TABLE I.—THE RAPID (First Set—89 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS.
											Bow	Stern			PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
1	RAPID.	56 58 58 05½ 59 09 14 1 16	*b* *c* *d* *e* *f*	67½ 63½ 65 62	3·33 3·54 3·46 3·63	33 39 38·5 37·1	4·89 5·20 5·08 5·32	One Horse.	7 passengers, = *c. q. lb.* 9 2 1	unf. light	in. 12¼	in. 9	not obs.	not obs.	Weight of RAPID, when empty, 3 ton, 8cwt. 2qr. 20lb. Towing-line, 116ft. long, attached 4½ft. from bow, and passed through two pulleys. Load distributed from bow to stern.
2	RAPID.	5 53 7 03 8 17 9 20 10 22	*b* *c* *d* *e* *f*	60 64 63 62	3·75 3·52 3·57 3·63	30 25 31·3 30·4	5·50 5·16 5·24 5·32	do.	do.	fav. do.	do.	do.	do.	do.	
3	RAPID.	22 21 24 03 25 45 27 25½ 28 59	*b* *c* *d* *e* *f*	102 102 100½ 94½	2·21 2·21 2·24 2·38	24 23·5 23·5 23·5	3·24 3·24 3·28 3·49	One Man.	6 passengers, = *c. q. lb* 8 0 15	unf.	not obs.	not obs.	do.	do.	
4	RAPID.	33 54 35 28 36 57 38 27 40 00	*b* *c* *d* *e* *f*	94 89 90 93	2·39 2·53 2·50 2·42	19·4 18·25 18 18	3·51 3·71 3·67 3·55	do.	do.	fav.	do.	do.	do.	do.	
5	RAPID.	50 03 51 13½ 52 24½ 58 37 54 51	*b* *c* *d* *e* *f*	70½ 71 72½ 74	3·19 3·17 3·10 3·04	33·1 28·3 28 27·8	4·68 4·65 4·55 4·46	do.	do	unf.	do.	do.	do.	do.	
6	RAPID.	20 1 29½ 2 38 3 46 4 57	*b* *c* *d* *e* *f*	69½ 68½ 68 71	3·24 3·29 3·31 3·17	26·8 24·8 24·1 23	4·75 4·82 4·85 4·65	do.	7 passengers, = *c. q. lb.* 9 2 1	fav.	in. 12¼	in. 9	do.	do.	
7	RAPID.	23 14 23 55 24 37 25 14½ 25 50½	*b* *c* *d* *e* *f*	41 42 37½ 36	5·49 5·36 6·00 6·25	76·1 64·5 98·7 99·7	8·05 7·86 8·80 9·17	One Horse.	9 passengers, = *c. q. lb.* 12 0 25	unf.	not obs.	not obs.	do.	do.	Bad experiment from irregular draught.
8	RAPID.	35 08½ 35 46 36 23 37 00 33 38	*b* *c* *d* *e* *f*	38½ 37 37 38	5·84 6·08 6·08 5·92	95 97 89 84	8·57 8·92 8·92 8·68	do.	7 passengers, = *c. q. lb.* 9 2 1	fav.	in. 12¼	in. 9	do.	do.	

TABLE I. CONTINUED.—THE RAPID (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
9	RAPID.	43 30 44 05 44 40 45 15 45 51	*b* *c* *d* *e* *f*	35 35 35 36	6·43 6·43 6·43 6·25	104·4 105 104 99·6	9·43 9·43 9·43 9·17	One Horse.	7 passengers, and 10cwt. = *c. q. lb.* 19 2 1	fav.	11¼	11¼	not obs.	not obs.	
10	RAPID.	51 25 52 00 52 34½ 53 09 53 44	*b* *c* *d* *e* *f*	35 34½ 34½ 35	6·43 6·52 6·52 6·43	131 121 118 110·9	9·43 9·57 9·57 9·43	Two Horses	do.	do.	do.	do.	do.	do.	
11	RAPID.	2 10½ 2 36 2 57½ 3 19 3 40½	*b* *c* *d* *e* *f*	25½ 21½ 21½ 21½	8·82 10·47 10·47 10·47	261 302 299 286	12·94 15·35 15·35 15·35	do.	do.	do.	do.	do.	do.	do.	
12	RAPID.	10 53 11 16 11 37½ 11 59 12 21	*b* *c* *d* *e* *f*	23 21½ 21½ 22	9·78 10·47 10·47 10·23	294 293 297 278	14·35 15·35 15·35 15·00	do.	do.	do.	do.	do.	do.	do.	
13	RAPID.	19 51½ 20 13 20 33½ 20 54½ 21 17	*b* *c* *d* *e* *f*	21½ 20½ 21 22½	10·47 10·91 10·71 9·98	316 300 306·8 290·1	15·35 16·09 15·71 14·67	do.	do.	do.	do.	do.	do.	do.	
14	RAPID.	25 55½ 26 17 26 38 26 59½ 27 21	*b* *c* *d* *e* *f*	21½ 21 21½ 21½	10·47 10·71 10·47 10·47	298 290 295 290	15·35 15·71 15·35 15·35	do.	do.	do.	do.	do.	do.	do.	
15	RAPID.	39 00½ 39 45½ 40 31½ 41 16½ 42 00	*b* *c* *d* *e* *f*	45 46 45 43½	5·00 4·89 5·00 5·17	73 71 78·7 72·5	7·33 7·17 7·33 7·59	do.	do.	do.	do.	do.	do.	do.	
16	RAPID.	49 13½ 50 06 50 54½ 51 41 52 26	*b* *c* *d* *e* *f*	52½ 48½ 46½ 45	4·29 4·64 4·84 5·00	54·0 61·9 62·9 70·3	6·29 6·80 7·10 7·33	do.	do.	do.	do.	do.	do.	do.	
17	RAPID.	19 28 20 15 21 03 21 52 22 42½	*b* *c* *d* *e* *f*	47 48 49 50½	4·79 4·69 4·59 4·46	68 56 60·2 55·7	7·02 6·88 6·73 6·53	do.	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	do.	12¼	12¼	do.	do.	Heavy Rain.

TABLE I. continued.—THE RAPID (First Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
											Bow	Stern			
		min. sec.		sec.	miles.	lbs.	feet.								
18	Rapid.	29 18 30 04½ 30 52 31 39 32 30½	b c d e f	46½ 48½ 47 50½	4·84 4·64 4·79 4·46	68 63·9 68·8 52·2	7·10 6·80 7·02 6·53	Two Horses.	7 passengers, and 1 ton.= *c. q. lb.* 29 2 1	fav.	in. 12¼	in. 12¼	not obs.	not obs.	
19	Rapid.	40 15½ 41 09 41 30½ 41 52 42 13½	b c d e f	23½ 21½ 21½ 21½	9·57 10·47 10·47 10·47	308 308 310 300	14·04 15·35 15·35 15·35	do.	do.	light	do.	do.	do.	do.	
20	Rapid.	7 15 7 38 8 00 8 22 8 43	b c d e f	23 22 22 21	9·78 10·23 10·23 10·71	292 289 292 296	14·35 15·00 15·00 15·71	do.	do.	do.	do.	do.	do.	do.	
21	Rapid.	14 11 14 39 15 08 15 37 16 06½	b c d e f	28 29 29 29½	8·03 7·76 7·76 7·59	312 327 350 ? 356 ?	11·79 11·38 11·38 11·19	do.	7 passengers, and 4¼ton,= *c. q. lb.* 94 2 1	none	17	17	do.	do.	Tractive power doubtful. See Remark, Experiment, No. 44.
22	Rapid.	23 22½ 23 49½ 24 17½ 24 46 25 14½	b c d e f	27 28 29 28½	8·33 8·03 7·76 7·90	325 332 342 344	12·22 11·79 11·38 11·58	do.	do.	do.	do.	do.	do.	do.	
23	Rapid.	32 19 33 08 33 50 34 35 35 23½	b c d e f	49 42 45 48½	4·59 5·36 5·00 4·64	59·6 118 61·8 69·8	6·73 7·86 7·33 6·80	do.	do.	do.	do.	do.	do.	do.	Bad experiment. Horses going irregularly.
24	Rapid.	41 32½ 42 24½ 43 16 44 07 44 55	b c d e f	52 51½ 51 48	4·33 4·37 4·41 4·69	74 52 57 70	6·35 6·41 6·47 6·88	do.	do.	do.	do.	do.	do.	do.	
25	Rapid.	42 55½ 43 23½ 43 52 44 21½ 44 51	b c d e f	28 29½ 29½ 29½	8·03 7·59 7·59 7·59	355 ? 356 ? 360 ? 363 ?	11·79 11·19 11·19 11·19	do.	do.	do.	do.	do.	do.	do.	Bad experiment. Boy off horse. Tractive power doubtful. See Remark, Experiment, No. 44.
26	Rapid.	3 11½ 3 34 3 58 4 21 4 44	b c d e f	22½ 24 23 23	10·00 9·38 9·78 9·78	360 ? 348 351 ? 353 ?	14·67 13·75 14·35 14·35	do.	do.	do.	do.	do.	do.	do.	do.

TABLE I. CONTINUED.—THE RAPID (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
27	RAPID.	13 23	*b*	23	9·78	374 ?	14·35	Two Horses.	7 passengers, and $4\frac{1}{4}$ ton, = *c. q. lb.* 94 2 1	none	in. 17	in. 17	not obs.	not obs.	Tractive Power doubtful. See Remark, Experiment, No. 44.
		13 46	*c*	$23\frac{1}{2}$	9·57	369 ?	14·04								
		14 $09\frac{1}{2}$	*d*	25	9·00	366 ?	13·20								
		14 $34\frac{1}{2}$	*e*	27	8·33	365 ?	12·22								
		15 $01\frac{1}{2}$	*f*												
28	RAPID.	27 51	*b*	$23\frac{1}{2}$	9·57	364 ?	14·04	do.	do.	do.	do.	do.	do.	do.	do.
		28 $14\frac{1}{2}$	*c*	25	9·00	345 ?	13·20								
		28 $39\frac{1}{2}$	*d*	$26\frac{1}{2}$	8·49	354 ?	12·45								
		29 06	*e*	$28\frac{1}{2}$	7·90	355 ?	11·58								
		29 $34\frac{1}{2}$	*f*												
29	RAPID.	56 $50\frac{1}{2}$	*b*	26	8·65	354 ?	12·69	do.	do.	do.	do.	do.	do.	do.	do.
		57 $16\frac{1}{2}$	*c*	26	8·65	356 ?	12·69								
		57 42	*d*	$28\frac{1}{2}$	7·90	363 ?	11·58								
		58 $10\frac{1}{2}$	*e*	28	8·03	366·4	11·79								
		58 $38\frac{1}{2}$	*f*												
30	RAPID.	6 $19\frac{1}{2}$	*b*	$28\frac{1}{2}$	7·90	316	11·58	do.	do.	unf. light	do.	do.	do.	do.	
		6 48	*c*	$29\frac{1}{2}$	7·59	324	11·19								
		7 $17\frac{1}{2}$	*d*	$28\frac{1}{2}$	7·90	340	11·58								
		7 46	*e*	$28\frac{1}{2}$	7·90	341	11·58								
		8 $14\frac{1}{2}$	*f*												
31	RAPID.	23 31	*b*	87	2·59	31	3·79	One Man.	do.	fav. light	do.	do.	do.	do.	
		24 58	*c*	$75\frac{1}{2}$	2·98	34	4·37								
		26 $13\frac{1}{2}$	*d*	$87\frac{1}{2}$	2·57	30	3·77								
		27 41	*e*	79	2·85	30	4·18								
		29 00	*f*												
32	RAPID.	37 09	*b*	87	2·59	27	3·79	do.	do.	do.	do.	do.	do.	do.	
		38 36	*c*	88	2·56	25	3·75								
		40 04	*d*	88	2·56	26	3·75								
		41 32	*e*	88	2·56	25	3·75								
		43 00	*f*												
33	RAPID.		*b*					Two Horses.	7 passengers, and $3\frac{1}{2}$ ton, = *c. q. lb.* 79 2 1	do.	16	16	do.	do.	Tractive Power doubtful. See Remark, Experiment, No. 44.
		13 21	*c*	22	10·23	354 ?	15·00								
		13 43	*d*	22	10·23	351 ?	15·00								
		14 05	*e*												
			f												
34	RAPID.	19 59	*b*	$23\frac{1}{2}$	9·57	358 ?	14·04	do.	6 passengers, and $3\frac{1}{2}$ ton, = *c. q. lb.* 78 0 15	do.	not obs.	not obs.	do.	do.	do.
		20 $22\frac{1}{2}$	*c*	$22\frac{1}{2}$	10·00	353 ?	14·67								
		20 45	*d*	$24\frac{1}{2}$	9·18	334	13·47								
		21 $09\frac{1}{2}$	*e*	$23\frac{1}{2}$	9·57	334	14·04								
		21 33	*f*												
35	RAPID.	31 $27\frac{1}{2}$	*b*	$27\frac{1}{2}$	8·18	328	12·00	do.	7 passengers, and $3\frac{1}{2}$ ton, = *c. q. lb.* 79 2 1	do.	16	16	do.	do.	do.
		31 55	*c*	$27\frac{1}{2}$	8·18	337	12·00								
		32 $22\frac{1}{2}$	*d*	$28\frac{1}{2}$	7·90	351 ?	11·58								
		32 51	*e*	28	8·03	357 ?	11·79								
		33 19	*f*												

TABLE I. continued.—THE RAPID (First Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
36	Rapid.	38 14 38 41 39 09½ 39 37 40 06	*b* *c* *d* *e* *f*	27 28½ 28½ 29	8·33 7·90 7·90 7·76	326 333 341 348	12·22 11·58 11·58 11·38	Two Horses.	7 passengers, and 3½ ton, = *c. q. lb.* 79 2 1	fav. light	in. 16	in. 16	not obs.	not obs.	
37	Rapid.	46 01 46 30½ 47 00½ 47 32½ 48 03½	*b* *c* *d* *e* *f*	29½ 29 32 31	7·59 7·76 7·03 7·26	238 249 245 238	11·19 11·38 10·31 10·65	do.	do.	do.	do.	do.	do.	do.	
38	Rapid.	55 41 56 12½ 56 44 57 15 57 46	*b* *c* *d* *e* *f*	31½ 31½ 31 31	7·14 7·14 7·26 7·26	274 247 256 243	10·48 10·48 10·65 10·65	do.	do.	unf. light	do.	do.	do.	do.	Heavy rain.
39	Rapid.	7 03 7 51½ 8 42 9 35 10 28	*b* *c* *d* *e* *f*	48½ 50½ 53 53	4·64 4·46 4·25 4·25	65 67 59 62	6·80 6·53 6·23 6·23	do.	do.	fav. light	do.	do.	do.	do.	Light rain.
40	Rapid.	17 21 18 27 19 35 20 41 21 45	*b* *c* *d* *e* *f*	66 68 66 64	3·41 3·31 3·41 3·52	46.4 44 45 46	5·00 4·85 5·00 5·16	do.	do.	none	do.	do.	do.	do.	
41	Rapid.	15 31½ 15 55½ 16 18 16 39½ 17 01	*b* *c* *d* *e* *f*	24 22½ 21½ 21½	9·38 10·00 10·47 10·47	366? 376? 376? 375?	13·75 14·67 15·35 15·35	do.	do.	fav. light	do.	do.	do.	do.	Tractive power doubtful. See Remark, Experiment, No. 44. Boat grazed.
42	Rapid.	22 57 23 23½ 23 48 24 13½ 24 39½	*b* *c* *d* *e* *f*	25½ 24½ 25½ 26	8·82 9·18 8·82 8·65	335 357? 367? 365?	12·94 13·47 12·94 12·69	do.	do.	unf. strng brze.	do.	do.	do.	do.	Tractive power doubtful. See Remark, Experiment, No. 44.
43	Rapid.	28 32 29 00 29 30 29 59 30 28	*b* *c* *d* *e* *f*	28 30 29 29	8·03 7·50 7·76 7·76	337 328 337 338	11·79 11·00 11·38 11·38	do.	do.	fav.	do.	do.	do.	do.	
44	Rapid.	39 32½ 40 02½ 40 33 41 03½ 41 33½	*b* *c* *d* *e* *f*	30 30½ 30½ 30	7·50 7·38 7·38 7·50	317 314 316 307	11·00 10·82 10·82 11·00	do.	do.	unf.	do.	do.	do.	do.	Observed that the piston of the dynamometer had not range enough, therefore all preceding experiments, in which the tractive power exceeds 350lb., are doubtful. Gave sufficient range to the piston.

TABLE I. CONTINUED.—THE RAPID (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
45	RAPID.	49 28½ 49 57 50 26½ 51 11 51 38	*b* *c* *d* *e* *f*	29½ 29½ 27	7·59 7·59 8·33	316 324	11·19 11·19 12·22	Two Horses.	7 passengers, and 3½ ton, = *c. q. lb.* 79 2 1	fav.	16	16	not obs.	not obs.	Bad experiment. Horse broke loose.
46	RAPID.	56 56 57 28 57 57½ 58 29 59 59½	*b* *c* *d* *e* *f*	32 29½ 32½ 30½	7·03 7·59 6·91 7·38	274 278 279 291	10·31 11·19 10·15 10·82	do.	do.	unf.	do.	do.	do.	do.	
47	RAPID.	2 42 3 03½ 3 24 3 44 4 05½	*b* *c* *d* *e* *f*	21½ 20½ 20 20½	10·47 10·93 11·25 10·93	497 498 486 469	15·35 16·09 16·50 16·09	do.	do.	fav.	do.	do.	do.	do.	
48	RAPID.	12 35 12 58 13 20 13 42½ 14 04½	*b* *c* *d* *e* *f*	23 22 22½ 22	9·78 10·23 10·00 10·23	466 426 416 417	14·35 15·00 14·67 15·00	do.	do.	unf.	do.	do.	do.	do.	
49	RAPID.	39 37½ 40 01½ 40 24 40 46 41 08½	*b* *c* *d* *e* *f*	24 22½ 22 22½	9·38 10·00 10·23 10·00	437 451 428 427	13·75 14·67 15·00 14·67	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	fav.	17	17	do.	do.	
50	RAPID.	46 53 47 17½ 47 42 48 06½ 48 32½	*b* *c* *d* *e* *f*	24½ 24½ 24½ 26	9·18 9·18 9·18 8·65	435 433 426 428	13·47 13·47 13·47 12·69	do.	do.	unf.	do.	do.	do.	do.	
51	RAPID.	8 25 8 53 9 22½ 9 52½ 10 22½	*b* *c* *d* *e* *f*	28 29½ 30 30	8·03 7·59 7·50 7·50	343 344 350 332	11·79 11·19 11·00 11·00	do.	do.	fav. light	do.	do.	do.	do.	Warm sunshine.
52	RAPID.	16 16 16 47 17 18 17 47½ 18 18½	*b* *c* *d* *e* *f*	31 31 28½ 31	7·26 7·26 7·90 7·26	291 286 309 304·5	10·65 10·65 11·58 10·65	do.	do.	unf.	do.	do.	do.	do.	
53	RAPID.	21 22 21 53 22 25 22 54½ 23 25½	*b* *c* *d* *e* *f*	31 32 29½ 29	7·26 7·03 7·59 7·76	321 305 326 310	10·65 10·31 11·19 11·38	do.	do.	fav.	do.	do.	do.	do.	

TABLE I. continued.—THE RAPID (First Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
54	Rapid.	35 07	*b*	33	6·82	269	10·00	Two Horses.	7 passengers, and 4¼ ton, = c. q. lb. 94 2 1	fav. light	in. 17	in. 17	not obs.	not obs.	
		35 40	*c*	32	7·03	237	10·31								
		36 12	*d*	30	7·50	273	11·00								
		36 42	*e*	32	7·03	286	10·31								
		37 14	*f*												
55	Rapid.	43 37	*b*	52	4·33	66	6·35	One Horse. Boy leading	do.	do.	do.	do.	do.	do.	
		44 29	*c*	51½	4·37	60	6·41								
		45 20½	*d*	51½	4·37	67	6·41								
		46 12	*e*	50	4·50	62	6·60								
		47 02	*f*												
56	Rapid.	58 49	*b*	66	3·41	54	5·00	do.	do.	do.	do.	do.	do.	do.	
		59 55	*c*	64½	3·49	49	5·12								
		1 00½	*d*	66½	3·38	46	4·96								
		2 07	*e*	63	3·57	56	5·24								
		3 10	*f*												
57	Rapid.	9 37	*b*	22½	10·00	487	14·67	Two Horses.	do.	fav. very light	do.	do.	do.	do.	
		9 59½	*c*	23	9·78	457	14·35								
		10 22½	*d*	22½	10·00	446	14·67								
		10 45	*e*	22½	10·00	421	14·67								
		11 07½	*f*												
58	Rapid.	16 04	*b*	23½	9·57	445	14·04	do.	do.	unf. very light	do.	do.	do.	do.	
		16 27½	*c*	24	9·38	419	13·75								
		16 51½	*d*	25	9·00	421	13·20								
		17 16½	*e*	26½	8·49	417	12·45								
		17 43	*f*												
59	Rapid.	37 46½	*b*	27½	8·18	391	12·00	do.	do.	do.	19½	15½	do.	do.	Weight shifted forward.
		38 14	*c*	26½	8·49	383	12·45								
		38 41½	*d*	28½	7·90	405	11·58								
		39 10	*e*	29	7·76	402	11·38								
		39 39	*f*												
60	Rapid.	44 28	*b*	27	8·33	388	12·22	do	do.	do. light	do.	do.	do.	do.	
		44 55	*c*	30	7·50	404	11·00								
		45 25	*d*	29	7·76	416	11·38								
		45 54	*e*	29½	7·59	409	11·19								
		46 23½	*f*												
61	Rapid.	9 34	*b*	28	8·03	412	11·79	do.	do.	fav. very light	do.	do.	do.	do.	
		10 02	*c*	29	7·76	410	11·38								
		10 31	*d*	29	7·76	437	11·38								
		11 00	*e*	29½	7·59	430	11·19								
		11 29½	*f*												
62	Rapid.	16 37½	*b*	28½	7·90	356	11·58	do.	do.	unf. very light	do.	do.	do.	do.	
		17 06	*c*	30	7·50	364	11·00								
		17 36	*d*	29½	7·59	378·9	11·19								
		18 05½	*e*	30	7·50	353	11·00								
		18 35½	*f*												

TABLE I. continued.—THE RAPID (First Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P.
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
63	Rapid.	33 02 33 30 33 59 34 27½ 34 56	*b* *c* *d* *e* *f*	28 29 28½ 28½	8·03 7·76 7·90 7·90	403 384 419 430	11·79 11·38 11·58 11·58	Two Horses	7 passengers, and 4¼ tons, = *c. q. lb.* 94 2 1	unf. very light	in. 19½	in. 15½	not obs.	not obs.	Towing-line attached 5½ ft. from bow.
64	Rapid.	49 41 50 10½ 50 40 51 10½ 51 40	*b* *c* *d* *e* *f*	29½ 29½ 30½ 29½	7·59 7·59 7·38 7·59	386·8 413 414·6 428	11·19 11·19 10·82 11·19	do.	do.	do.	do.	do.	do.	do.	Towing-line taken through one pulley only, and 4 ft. 1 in. from the bow.
65	Rapid.	28 54 29 21 29 49 30 18 30 46½	*b* *c* *d* *e* *f*	27 28 29 28½	8·33 8·03 7·76 7·90	316 323 360·6 367·8	12·22 11·79 11·38 11·58	do.	do.	do.	do.	do.	do.	do.	Outrigger used 6 ft. 4 in. from the gunwale, and 5 ft. from the bow.
66	Rapid.	42 51 43 21 43 50½ 44 20 44 50½	*b* *c* *d* *e* *f*	30 29½ 29½ 30½	7·50 7·59 7·59 7·38	295·6 292·3 315·2 301·4	11·00 11·19 11·19 10·82	do.	do.	do.	do.	do.	do.	do.	No outrigger.
67	Rapid.	18 31 19 01 19 32 20 02 20 33	*b* *c* *d* *e* *f*	30 31 30 31	7·50 7·26 7·50 7·26	303 272·5 281 261	11·00 10·65 11·00 10·65	do.	do.	do.	do.	do.	do.	do.	Outrigger, 3 ft. 8 in. from gunwale, 5 ft. 6 in. from bow.
68	Rapid.	31 55 32 21½ 32 48 33 17 33 45	*b* *c* *d* *e* *f*	26½ 26½ 29 28	8·49 8·49 7·76 8·03	366 378 382·6 419	12·45 12·45 11·38 11·79	do.	do.	do.	do.	do.	do.	do.	
69	Rapid.	53 20 53 48 54 17 54 45 54 13½	*b* *c* *d* *e* *f*	28 29 28 28½	8·03 7·76 8·03 7·90	468 438·5 473·5 477·7	11·79 11·38 11·79 11·58	do.	do.	fav. light	do.	do.	do.	do.	Towing-line from the bow.
70	Rapid.	18 44½ 1 13½ 1 41 2 09	*b* *c* *d* *e* *f*	26½ 29 27½ 28	8·49 7·76 8·18 8·03	328·4 314·2 386·4 365	12·45 11·38 12·00 11·79	do.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	none	15⅜	15⅜	do.	do.	A barge passed at 1 m. 12 s.
71	Rapid.	8 10½ 8 37 9 05½ 9 33 10 01½	*b* *c* *d* *e* *f*	27½ 28½ 27½ 27½	8·18 7·90 8·18 8·18	326·6 351·1 362·6 364·7	12·00 11·58 12·00 12·00	do.	do.	unf. light	do.	do.	do.	do.	

TABLE I. CONTINUED.—THE RAPID (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS.
											Bow	Stern			PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
72	RAPID.	13 54½ 14 21 14 48 15 16 15 44	b c d e f	26½ 27 28 28	8·49 8·33 8·03 8·03	337 339 358 365	12·45 12·22 11·79 11·79	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	unf. light	in. 15⅜	in. 15⅜	not obs.	not obs.	
73	RAPID.	26 03 27 11 27 39 28 07½ 29 36½	b c d e f	28 28 28½ 29	8·03 8·03 7·90 7·76	289·3 301·5 318·3 312·4	11·79 11·79 11·58 11·38	do.	do.	do.	do.	do.	do.	do.	
74	RAPID.	57 51 58 18 58 46 59 15 59 43	b c d e f	27 28 29 28	8·33 8·03 7·76 8·03	335·7 335·5 351·4 382·6	12·22 11·79 11·38 11·79	do.	do.	do.	do.	do.	do.	do.	
75	RAPID.	10 19 10 43 11 09 11 34 11 59	b c d e f	24 26 25 25	9·38 8·65 9·00 9·00	396·3 363 406·4 410	13·75 12·69 13·20 13·20	do.	do.	do.	do.	do.	do.	do.	
76	RAPID.	25 29 25 55½ 26 22 26 50 27 18	b c d e f	26½ 26½ 28 28	8·49 8·49 8·03 8·03	386·5 384·5 393·5 405·5	12·45 12·45 11·79 11·79	do.	do.	do.	do.	do.	do.	do.	
77	RAPID.	37 07 37 35½ 38 04½ 38 33 39 02½	b c d e f	28½ 29 28½ 29½	7·90 7·76 7·90 7·59	319·4 307·4 346·3 348·8	11·58 11·38 11·58 11·19	do.	do.	do.	do.	do.	do.	do.	
78	RAPID.	49 52 50 14 50 35 50 56 51 17	b c d e f	22 21 21 21	10·23 10·71 10·71 10·71	474·1 454·5 438 440·6	15·00 15·71 15·71 15·71	do.	do.	do.	do.	do.	do.	do.	
79	RAPID.	6 48 7 44 8 41 9 39 10 38	b c d e f	56 57 58 59	4·02 3·95 3·88 3·81	64·6 56 53·7 52·6	5·89 5·78 5·69 5·59	Two Men.	do.	do.	do.	do.	do.	do.	
80	RAPID.	53 28 53 58 54 26 54 55 55 24	b c d e f	30 28 29 29	7·50 8·03 7·76 7·76	253 280·8 301 292·3	11·00 11·79 11·38 11·38	Two Horses.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	do.	14	14	do.	do.	

TABLE I. continued—THE RAPID (First Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
81	Rapid.	22 05 22 30½ 22 55½ 23 20½ 23 46	*b* *c* *d* *e* *f*	25½ 25 25 25½	8·82 9·00 9·00 8·82	337·3 355·8 356·5 351·2	12·94 13·20 13·20 12·94	Two Horses.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	fav. light	in. 14	in. 14	not obs.	not obs.	
82	Rapid.	36 25 36 44 37 03½ 37 23½ 37 44	*b* *c* *d* *e* *f*	19 19½ 20 20½	11·84 11·54 11·25 10·93	482 483·2 461 434·5	17·37 16·92 16·50 16·09	do.	do.	do.	do.	do.	do.	do.	
83	Rapid.	56 26 57 32 58 35 59 38 40½	*b* *c* *d* *e* *f*	66 63 63 62½	3·41 3·57 3·57 3·60	47 44 43·5 41	5·00 5·24 5·24 5·28	Two Men.	do.	do.	do.	do.	do.	do.	
84	Rapid.	30 06½ 30 27 30 47½ 31 08 31 28½	*b* *c* *d* *e* *f*	20½ 20½ 20½ 20½	10·93 10·93 10·93 10·93	420 372 380·8 374·8	16·09 16·09 16·09 16·09	Two Horses.	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	fav. strng	12⅛	12⅛	do.	do.	
85	Rapid.	40 45 41 11 41 35½ 42 00½ 42 26½	*b* *c* *d* *e* *f*	26 24½ 25 26	8·65 9·18 9·00 8·65	302·3 300 294·2 300	12·69 13·47 13·20 12·69	do.	do.	do.	do.	do.	do.	do.	
86	Rapid.	55 32 56 00 56 28 56 56 57 25½	*b* *c* *d* *e* *f*	28 28 28 29½	8·03 8·03 8·03 7·59	234·6 242·2 261·3 250·6	11·79 11·79 11·79 11·19	do.	do.	do.	do.	do.	do.	do.	
87	Rapid.	6 18 7 16½ 8 12½ 9 11 10 08	*b* *c* *d* *e* *f*	58½ 56 58½ 57	3·84 4·02 3·84 3·95	45·2 45·7 41·7 43·8	5·64 5·89 5·64 5·78	One Horse. Boy leading	do.	do.	do.	do.	do.	do.	
88	Rapid.	27 45 28 46 29 42 30 40 31 36½	*b* *c* *d* *e* *f*	61 56 58 56½	3·69 4·02 3·88 3·98	56·8 45·1 42 42	5·41 5·90 5·69 5·84	Two Men.	do.	fav. light	do.	do.	do.	do.	
89	Rapid.	51 21 51 46 52 10½ 52 36 53 01	*b* *c* *d* *e* *f*	25 24½ 25½ 25	9·00 9·18 8·82 9·00	263·6 264·4 248 255	13·20 13·47 12·94 13·20	Two Horses.	7 passengers, = *c. q. lb.* 9 2 1	do.	12¼	9	do.	do.	

TABLE II.—THE ZEPHYR (First Set—36 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
											Bow	Stern			
		min. sec.		sec.	miles.	lbs.	feet.								
90	Zephyr.	5 03 5 52 6 42 7 33 8 27	*b* *c* *d* *e* *f*	49 50 51 54	4·59 4·50 4·41 4·17	35·5 38·4 41·6 39·1	6·73 6·60 6·47 6·11	Two Horses.	7 passengers, = *c. q. lb.* 9 2 1	fav. light	in. 7	in. 5	not obs.	not obs.	Weight of Zephyr, when empty, 2 ton, 2 cwt. 2 qr. 5lb. Towing-line 11 ft. from bow.
91	Zephyr.	16 35 17 00½ 17 26½ 17 54 18 20½	*b* *c* *d* *e* *f*	25½ 26 27½ 26½	8·82 8·65 8·18 8·49	175·5 169 164·6 155·6	12·94 12·69 12·00 12·45	do.	do.	do.	do.	do.	do.	do.	
92	Zephyr.	28 50½ 29 15 29 39 30 03 30 27	*b* *c* *d* *e* *f*	24½ 24 24 24	9·18 9·38 9·38 9·38	202 188·7 181·2 175·6	13·47 13·75 13·75 13·75	do.	do.	do.	do.	do.	do.	do.	
93	Zephyr.	39 10½ 39 27 39 44 40 01 40 18	*b* *c* *d* *e* *f*	17½ 17 17 17	12·86 13·24 13·24 13·24	347 343·8 349 349	18·86 19·41 19·41 19·41	do.	do.	do.	do.	do.	do.	do.	
94	Zephyr.	39 20 39 39 39 57 40 15 40 33	*b* *c* *d* *e* *f*	19 18 18 18	11·84 12·50 12·50 12·50	357·5 360 372·8 361	17·37 18·33 18·33 18·33	do.	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	do.	8¼	7¼	do.	do.	
95	Zephyr.	47 04 47 28½ 47 52 48 17 48 40½	*b* *c* *d* *e* *f*	24½ 23½ 25 23½	9·18 9·57 9·00 9·57	237·4 230·5 211 222·7	13·47 14·04 13·20 14·04	do.	do.	do.	do.	do.	do.	do.	
96	Zephyr.	1 15½ 2 17 3 14½ 4 13½ 5 18	*b* *c* *d* *e* *f*	61½ 57½ 59 64½	3·66 3·91 3·81 3·49	36·5 42·7 34·9 31·5	5·37 5·74 5·59 5·12	One Horse. Boy leading	do.	do.	do.	do.	do.	do.	
97	Zephyr.	13 59½ 14 52½ 15 45½ 16 38 17 32	*b* *c* *d* *e* *f*	53 53 53½ 54	4·25 4·25 4·21 4·17	47 46 38 39	6·23 6·23 6·17 6·11	One Horse. Boy riding.	do.	do.	do.	do.	do.	do.	
98	Zephyr.	47 23½ 47 42 48 00½ 48 19½ 48 38	*b* *c* *d* *e* *f*	18½ 18½ 19 18½	12·16 12·16 11·84 12·16	370 370·8 360 369·2	17·84 17·84 17·37 17·84	Two Horses.	7 passengers, & 1 t. 6 cwt. = *c. q. lb.* 35 2 1	do.	9¼	7½	do.	do.	Zephyr, with 1 ton 6 cwt. and 7 passengers, nearly equal to the weight of the Rapid and 7 passengers.

TABLE II. CONTINUED.—THE ZEPHYR (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
99	ZEPHYR.	55 14 55 37½ 56 01½ 56 26 56 51	b c d e f	23½ 24 24½ 25	9·57 9·38 9·18 9·00	259·8 227·4 223 224·7	14·04 13·75 13·47 13·20	Two Horses.	7 passengers & 1t. 6cwt. = c. q. lb. 35 2 1	fav. light	in. 9¼	in. 7½	not obs.	not obs.	A barge passed, 56m. 40s.
100	ZEPHYR.	2 01 2 32½ 3 04 3 33½ 4 03½	b c d e f	31½ 31½ 29½ 30	7·14 7·14 7·59 7·50	138·5 152·5 167·2 156·9	10·48 10·48 11·19 11·00	do.	do.	do.	do.	do.	do.	do.	
101	ZEPHYR.	12 14½ 13 08 14 03 14 58 15 53	b c d e f	53½ 55 55 55	4·21 4·09 4·09 4·09	45·5 45·2 40 41·1	6·17 6·00 6·00 6·00	do.	do.	do.	do.	do.	do.	do.	
102	ZEPHYR.	34 22 34 41½ 35 00 35 19½ 35 39	b c d e f	19½ 18½ 19½ 19½	11·54 12·16 11·54 11·54	410·4 391·5 456·4 345·2	16·92 17·84 16·92 16·92	do.	7 passengers, and 2 ton, = c. q. lb. 49 2 1	do.	10	9	do.	do.	
103	ZEPHYR.	57 49 58 14 58 39 59 05 59 31	b c d e f	25 25 26 26	9·00 9·00 8·65 8·65	272 243·6 240·2 250·2	13·20 13·20 12·69 12·69	do.	do.	fav. very light	do.	do.	do.	do.	
104	ZEPHYR.	1 27 1 50 2 13 2 35½ 2 58	b c d e f	23 23 22½ 22½	9·78 9·78 10·00 10·00	317·7 281·2 274·8 252·8	14·35 14·35 14·67 14·67	do.	do.	do.	do.	do.	do.	do.	
105	ZEPHYR.	13 31½ 14 23½ 15 12½ 16 05 16 58	b c d e f	52 49 52½ 53	4·33 4·59 4·29 4·25	44·2 55·4 45·4 47·4	6·35 6·73 6·29 6·23	do.	do.	do.	do.	do.	do.	do.	
106	ZEPHYR.	48 49 49 44 50 40 51 36 52 31½	b c d e f	55 56 56 55½	4·09 4·02 4·02 4·05	54·1 50·9 47·8 48·8	6·00 5·89 5·89 5·95	Two Men.	7 passengers, and 3 ton, = c. q. lb. 69 2 1	do.	12	11	do.	do.	
107	ZEPHYR.	3 09 4 10 5 10½ 6 10½ 7 10½	b c d e f	61 60½ 60 60	3·69 3·72 3·75 3·75	92·8 76·4 69·7 65·8	5·41 5·45 5·50 5·50	do.	do.	do.	do.	do.	do.	do.	Stern drawn foremost.

TABLE II. CONTINUED.—THE ZEPHYR.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
108	ZEPHYR.	10 11 10 30 10 49½ 11 09 11 28	*b* *c* *d* *e* *f*	19 19½ 19½ 19	11·84 11·54 11·54 11·84	449·8 434·2 418·4 407·4	17·37 16·92 16·92 17·37	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	fav. light	12	11	not obs.	not obs.	
109	ZEPHYR.	20 58 21 25 21 51 22 18 22 45	*b* *c* *d* *e* *f*	27 26 27 27	8·33 8·65 8·33 8·33	272·3 262·7 299·5 291·3	12·22 12·69 12·22 12·22	do.	do.	do.	do.	do.	do.	do.	
110	ZEPHYR.	29 41 30 08 30 33 30 59 31 25	*b* *c* *d* *e* *f*	27 25 26 26	8·33 9·00 8·65 8·65	293·0 295·7 283·5 306·5	12·22 13·20 12·69 12·69	do.	do.	do.	do.	do.	do.	do.	
111	ZEPHYR.	20 12½ 20 34 20 55 21 16 21 36½	*b* *c* *d* *e* *f*	21½ 21 21 20½	10·47 10·71 10·71 10·97	441·1 418·2 406·4 423·4	15·35 15·71 15·71 16·09	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	do.	13¾	12¾	do.	do.	
112	ZEPHYR.	33 36 34 04½ 34 32 34 59 35 27	*b* *c* *d* *e* *f*	28½ 27½ 27 28	7·90 8·18 8·33 8·03	275·0 321·0 351·0 377·5	11·58 12·00 12·22 11·79	do.	do.	do.	do.	do.	do.	do.	
113	ZEPHYR.	42 54 43 49 44 42 45 33 46 24	*b* *c* *d* *e* *f*	55 53 51 51	4·09 4·25 4·41 4·41	59·8 59·8 62·7 57·6	6·00 6·23 6·47 6·47	do.	do.	do.	do.	do.	do.	do.	
114	ZEPHYR.	34 41 34 59 35 18 35 37 35 55	*b* *c* *d* *e* *f*	18 19 19 18	12·50 11·84 11·84 12·50	401·0 384·0 375·6 372·7	18·33 17·37 17·37 18·33	do.	7 passengers, & 1t. 13cwt. = *c. q. lb.* 42 2 1	do.	9¾	8½	do.	do.	1 ton 13cwt. made the ZEPHYR and 7 passengers nearly equal to the VELOCITY, with 7 passengers.
115	ZEPHYR.	17 03 17 26 17 48½ 18 11½ 18 33½	*b* *c* *d* *e* *f*	23 22½ 23 22	9·78 10·00 9·78 10·23	291·5 271·0 267·0 269·4	14·35 14·67 14·35 15·00	do.	do.	do.	do.	do.	do.	dur. run. bow elev. 11′	
116	ZEPHYR.	58 18 59 05 59 52 0 40 1 28½	*b* *c* *d* *e* *f*	47 47 48 48½	4·79 4·79 4·69 4·64	67·1 59·1 53·5 59·9	7·02 7·02 6·88 6·80	do.	do.	do.	do.	do.	do.		Bubble vibrating a little.

TABLE II. CONTINUED.—THE ZEPHYR.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
117	ZEPHYR.	8 52 9 55 10 55 11 52 12 47	*b* *c* *d* *e* *f*	63 60 57 55	3·57 3·75 3·95 4·09	37·8 39·9 50·2 42·0	5·24 5·50 5·78 6·00	Two Horses.	7 passengers, & 1t. 13 cwt. = *c. q. lb.* 42 2 1	fav. light	in. 9$\frac{3}{4}$	in. 8$\frac{1}{2}$	not obs.		
118	ZEPHYR.	19 52 20 10 20 28$\frac{1}{2}$ 20 47 21 06	*b* *c* *d* *e* *f*	18 18$\frac{1}{2}$ 18$\frac{1}{2}$ 19	12·50 12·16 12·16 11·84	414·5 386·3 372·0 372·0	18·33 17·84 17·84 17·37	do.	do.	do.	do.	do.	do.	dur. run. bow elev. 27′	
119	ZEPHYR.	38 52 39 15 39 37$\frac{1}{2}$ 40 00 40 23	*b* *c* *d* *e* *f*	23 22$\frac{1}{2}$ 22$\frac{1}{2}$ 23	9·78 10·00 10·00 9·78	302·6 270·8 258·3 258·6	14·35 14·67 14·67 14·35	do.	do.	do.	11$\frac{1}{4}$	7$\frac{1}{4}$	do.	do. do. elev. 7$\frac{1}{2}$′	Weight shifted forward.
120	ZEPHYR.	51 20 51 44 52 07$\frac{1}{2}$ 52 30 52 53	*b* *c* *d* *e* *f*	24 23$\frac{1}{2}$ 22$\frac{1}{2}$ 23	9·38 9·57 10·00 9·78	280·8 259·2 266·7 250·6	13·75 14·04 14·67 14·35	do.	do.	do.	8$\frac{1}{4}$	10$\frac{1}{4}$	do.	do. do. elev. 15$\frac{1}{2}$′	do. aft.
121	ZEPHYR.	10 25 10 47 11 08$\frac{1}{2}$ 11 29 11 50$\frac{1}{2}$	*b* *c* *d* *e* *f*	22 21$\frac{1}{2}$ 20$\frac{1}{2}$ 21$\frac{1}{2}$	10·23 10·47 10·97 10·47	328·8 311·2 317·3 283·0	15·00 15·35 16·09 15·35	do.	do.	do.	9$\frac{1}{2}$	8$\frac{1}{2}$	do.	do. do. dep. 20′	Weight distributed equally.
122	ZEPHYR.	12 06$\frac{1}{2}$ 12 32 12 57 13 24 13 50	*b* *c* *d* *e* *f*	25$\frac{1}{2}$ 25 27 26	8·82 9·00 8·33 8·65	230·2 241·8 237·1 238·6	12·94 13·20 12·22 12·69	do.	do.	do.	do.	do.	do.	do. do. elev. 22′	
123	ZEPHYR.	21 18 21 41$\frac{1}{2}$ 22 06 22 30 22 53	*b* *c* *d* *e* *f*	23$\frac{1}{2}$ 24$\frac{1}{2}$ 24 23	9·57 9·18 9·38 9·78	257·5 253·0 256·7 245·2	14·04 13·47 13·75 14·35	do.	do.	do.	do.	do.	do.	do. do. elev. 22$\frac{1}{2}$′	
124	ZEPHYR.	34 27 34 51 35 16 35 40 36 03	*b* *c* *d* *e* *f*	24 25 24 23	9·38 9·00 9·38 9·78	246·0 253·6 255·2 249·0	13·75 13·20 13·75 14·35	do.	do.	do.	8	10	do.	do. do. elev. 26′	Weight shifted aft.
125	ZEPHYR.	50 54 51 18$\frac{1}{2}$ 51 41 52 09$\frac{1}{2}$ 52 35	*b* *c* *d* *e* *f*	23$\frac{1}{2}$ 25$\frac{1}{2}$ 25$\frac{1}{2}$ 25$\frac{1}{2}$	9·57 8·82 8·82 8·82	254·5 243·0 253·2 259·2	14·04 12·94 12·94 12·94	do.	do.	do.	11$\frac{1}{2}$	7$\frac{1}{4}$	do.	do. do. elev. 32′	Weight shifted forward.

TABLE III.—THE LARK (31 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per second.	Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
126	LARK.	1 18½ 1 36 1 57 2 17½ 2 38	*b* *c* *d* *e* *f*	17½ 21 20½ 20½	12·86 10·71 10·97 10·97	386·0 355·0 337·0 317·7	18·86 15·71 16·09 16·09	Two Horses	7 passengers, = *c. q. lb.* 9 2 1	fav. light	in. 10¼	in. 10¼	not obs.	dur. run. bow elev. 25½′	Weight of LARK, when empty, 3 ton 3 cwt. 1qr. 4lb.
127	LARK.	27 05 27 30 27 54 28 18½ 28 42	*b* *c* *d* *e* *f*	25 24 24½ 23½	9·00 9·38 9·18 9·57	256·5 253·6 256·1 264·8	13·20 13·75 13·47 14·04	do.	do.	do.	do.	do.	do.	do. do. elev. 15′	
128	LARK.	41 04 41 53 42 45 43 35 44 30½	*b* *c* *d* *e* *f*	49 52 50 54½	4·59 4·33 4·50 4·13	64·7 55·9 56·5 46·5	6·73 6·35 6·60 6·06	do.	do.	fav. stronger than last.	do.	do.	do.	do. do. level.	
129	LARK.	52 44 53 53 55 02 56 12 57 25	*b* *c* *d* *e* *f*	69 69 70 73	3·26 3·26 3·21 3·08	26·0 23·3 20·8 28·6	4·78 4·78 4·71 4·52	do.	do.	not steady.	do.	do.	do.	do.	
130	LARK.	18 30 18 48 19 08 19 27½ 19 47	*b* *c* *d* *e* *f*	18 20 19½ 20½	12·50 11·25 11·54 10·97	396·0 368·7 370·6 364·5	18·33 16·50 16·92 16·09	do.	7 passengers, and 5 cwt.= *c. q. lb.* 14 2 1	fav. light	10½	10½	do.	do. do. elev. 27′	5cwt. made the LARK and 7 passengers nearly equal to the RAPID, and 7 passengers.
131	LARK.	27 02½ 27 26½ 27 50 28 13½ 28 36	*b* *c* *d* *e* *f*	24 23½ 23½ 22½	9·38 9·57 9·57 10·00	279·7 270·8 251·5 265·0	13·75 14·04 14·04 14·67	do.	do.	do.	do.	do.	do.	do. do. elev. 17′	
132	LARK.	36 51½ 37 47 38 43 39 35 40 33	*b* *c* *d* *e* *f*	56½ 56 52 48	3·98 4·02 4·33 4·69	43·8 50·1 43·4 39·1	5·84 5·89 6·35 6·88	do.	do.	fav. stronger than last.	do.	do.	do.	do. do. elev. 3′	
133	LARK.	0 38 0 57 1 16½ 1 36 1 56	*b* *c* *d* *e* *f*	19 19½ 20½ 20	11·84 11·54 10·97 11·25	393·4 372·3 363·6 366·8	17·37 16·92 16·09 16·50	do.	7 passengers, and 12 cwt.= *c. q. lb.* 21 2 1	do.	11½	11½	do.	do. do. elev. 29′	12cwt. made the LARK, and 7 passengers nearly equal to the VELOCITY, and 7 passengers.
134	LARK.	8 46 9 09½ 9 33½ 9 57 10 20½	*b* *c* *d* *e* *f*	23½ 24 23½ 23½	9·57 9·38 9·57 9·57	286·2 280·2 278·5 265·6	14·04 13·75 14·04 14·04	do.	do.	fav. light	do.	do.	do.	do. do. elev. 19′	

TABLE III. CONTINUED.—THE LARK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P.
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
135	LARK.	22 35 23 33 24 30 25 27 26 24½	*b* *c* *d* *e* *f*	58 57 57 57½	3·88 3·95 3·95 3·91	34·6 35·2 45·5 39·2	5·69 5·78 5·78 5·74	Two Horses.	7 passengers, and 12 cwt. = *c. q. lb.* 21 2 1	fav. fresh breeze.	11½	11½	not obs.	dur. run. bow elev. 1½′	
136	LARK.	52 34 52 53½ 53 12½ 53 32 53 51½	*b* *c* *d* *e* *f*	19½ 19 19½ 19½	11·54 11·84 11·54 11·54	404·8 398·3 382·3 388·0	16·92 17·37 16·92 16·92	do.	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	do.	11¾	11¾	do.	do. do. elev. 24′	
137	LARK.	2 18½ 2 43 3 07 3 31 3 53	*b* *c* *d* *e* *f*	24½ 24 24 22	9·18 9·38 9·38 10·23	295·0 295·2 293·1 293·5	13·47 13·75 13·75 15·00	do.	do.	do.	do.	do.	do.	do. do. elev. 13′	
138	LARK.	14 45 15 40 16 39 17 37 18 34	*b* *c* *d* *e* *f*	55 59 58 57	4·09 3·81 3·88 3·95	37·0 36·5 35·0 36·0	6·00 5·59 5·69 5·78	do.	do.	do.	do.	do.	do.	do. do. level.	
139	LARK.	27 52 30 30 32 55 34 10 36 03	*b* *c* *d* *e* *f*					do.	do.	do.	do.	do.	do.		Boat drifted with the wind.
140	LARK.	44 45 45 05 45 26 45 47 46 07½	*b* *c* *d* *e* *f*	20 21 21 20½	11·25 10·71 10·71 10·97	435·0 415·0 393·0 387·0	16·50 15·71 15·71 16·09	do.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	do.	13½	13½	do.	do. do. elev. 29′	
141	LARK.	57 35½ 58 01 58 26 58 51½ 59 17	*b* *c* *d* *e* *f*	25½ 25 25½ 25½	8·82 9·00 8·82 8·82	338·7 334·0 329·0 334·7	12·94 13·20 12·94 12·94	do.	do.	do.	do.	do.	do.	do. do. elev. 26′	
142	LARK.	7 17 8 15 9 10½ 10 04 11 01	*b* *c* *d* *e* *f*	58 55½ 53½ 57	3·88 4·05 4·21 3·95	46·2 48·2 46·6 39·1	5·69 5·95 6·17 5·78	do.	do.	do.	do.	do.	do.	do. do. level.	
143	LARK.	36 01½ 36 23 36 44½ 37 06 37 27	*b* *c* *d* *e* *f*	21½ 21½ 21½ 21	10·47 10·47 10·47 10·71	448·7 422·6 400·0 401·0	15·35 15·35 15·35 15·71	do.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	do.	14¾	14¾	do.	do. do. elev.	

TABLE III. CONTINUED.—THE LARK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
144	LARK.	46 33 47 32 48 29 49 28 50 26	*b* *c* *d* *e* *f*	59 57 59 58	3·81 3·95 3·81 3·88	41·3 56·6 49·3 34·0	5·59 5·78 5·59 5·69	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	fav. fresh brze.	in. 14¾	in. 14¾	not obs.	dur. run. bow elev. 3½′	The towing-line dragged along the water a short distance.
145	LARK.	58 29 58 55 59 21½ 59 48 14	*b* *c* *d* *e* *f*	26 26½ 26½ 26	8·65 8·49 8·49 8·65	359·2 359·3 364·4 379·0	12·69 12·45 12·45 12·69	do.	do.	do.	do.	do.	do.	do. do. elev. 28′	
146	LARK.	41 46 42 11 42 36½ 43 05 43 36½	*b* *c* *d* *e* *f*	25 25½ 28½ 31½	9·00 8·82 7·90 7·14	432·3 408·0 380·6 372·1	13·20 12·94 11·58 10·48	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	fav. very light	16½	16½	do.	do. do. elev. 30′	
147	LARK.	56 05 57 07 58 10 59 13 14	*b* *c* *d* *e* *f*	62 63 63 61	3·63 3·57 3·57 3·69	47·3 43·2 56·8 45·8	5·32 5·24 5·24 5·41	do.	do.	do.	do.	do.	do.	do. do. level	
148	LARK.	9 29½ 10 01 10 35½ 11 08½ 11 41	*b* *c* *d* *e* *f*	31½ 34½ 33 33½	7·14 6·52 6·82 6·72	248·5 181·6 195·2 176·7	10·48 9·57 10·00 9·85	do.	do.	do.	do.	do.	do.	do. do. elev. 5′	
149	LARK.	24 36 25 02 25 28 25 54 26 24	*b* *c* *d* *e* *f*	26 26 26 30	8·65 8·65 8·65 7·50	421·2 413·4 432·4 419·5	12·69 12·69 12·69 11·00	do.	do.	do.	do.	do.	do.	not obs.	
150	LARK.	12 05½ 12 29½ 12 52 13 14½ 13 37	*b* *c* *d* *e* *f*	24 23½ 22½ 22½	9·38 9·57 10·00 10·00	463·7 456·2 430·7 412·0	13·75 14·04 14·67 14·67	do	do.	do.	do.	do.	do.	do. do. elev. 45′	
151	LARK.	22 07½ 22 34½ 23 01½ 23 29 23 57	*b* *c* *d* *e* *f*	27 27 27½ 28	8·33 8·33 8·18 8·03	377·8 377·5 402·6 422·0	12·22 12·22 12·00 11·79	do.	do.	do.	do.	do.	do.	do. do. elev. 37′	
152	LARK.	39 28 39 51 40 13½ 40 36 40 57	*b* *c* *d* *e* *f*	23 22½ 22½ 21	9·78 10·00 10·00 10·71	474·0 458·2 431·0 424·7	14·35 14·67 14·67 15·71	do.	do.	do.	18	15	do.	do. do. elev. 34′	Weight shifted forward.

TABLE III. CONTINUED.—THE LARK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
153	LARK.	52 35 53 02½ 53 30½ 53 58 54 26	*b* *c* *d* *e* *f*	27½ 28 28½ 28	8·18 8·03 7·90 8·03	398·3 382·1 413·0 426·0	12·00 11·79 11·58 11·79	Two Horses.	7 passengers, and 4¼ ton,= *c. q. lb.* 94 2 1	fav. light	in. 18	in. 15	not obs.	dur. run. bow elev. 35′	
154	LARK.	6 13½ 7 10 8 08 9 08 10 11	*b* *c* *d* *e* *f*	56½ 58 60 63	3·98 3·88 3·75 3·57	50·9 55·6 44·8 40·6	5·84 5·69 5·50 5·24	do.	do.	do.	do.	do.	do.	do. do. level.	
155	LARK.	37 53 38 17½ 38 40½ 39 03½ 39 26½	*b* *c* *d* *e* *f*	24½ 23 23 23	9·18 9·78 9·78 9·78	444·4 449·3 436·0 422·2	13·47 14·35 14·35 14·35	do.	do.	do.	14¾	17¾	do.	do. do. elev. 32′	Weight shifted aft.
156	LARK.	59 03 59 26 59 50 12 35	*b* *c* *d* *e* *f*	23 24 22 23	9·78 9·38 10·23 9·78	479·0 460·5 449·2 439·7	14·35 13·75 15·00 14·35	do.	do.	fav. very light	19½	13	do.	do. do. elev. 5′. At rest. depd 4′	Weight shifted forward. Towing-line 5 ft. from the Stern. Dynamometer 5 ft. 6 in. from the bow.

TABLE IV.—THE VELOCITY (23 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
											Bow.	Stern			
		min. sec.		sec.	miles.	lbs.	feet.								
157	VELOCITY.	14 16 14 36 14 55½ 15 15 15 35½	*b* *c* *d* *e* *f*	20 19½ 19½ 20½	11·25 11·54 11·54 10·97	407·8 396·7 382·3 375·1	16·50 16·92 16·92 16·09	Two Horses.	7 passengers, = *c. q. lb.* 9 2 1	not obs.	in. 11	in. 8	not obs.	dur. run. bow elev. 43′	Weight of VELOCITY, when empty, 3 ton. 15cwt. 2qr. 9lb.
158	VELOCITY.	29 38 30 04 30 29 30 53 31 19½	*b* *c* *d* *e* *f*	26 25 24 26½	8·65 9·00 9·38 8·49	283·0 267·2 259·6 261·4	12·69 13·20 13·75 12·45	do.	do.	do.	do.	do.	do.	do. do. elev. 29′	
159	VELOCITY.	59 13 59 31½ 59 51 11 29½	*b* *c* *d* *e* *f*	18½ 19½ 20 18½	12·16 11·54 11·25 12·16	440·5 415·2 383·4 382·4	17·84 16·92 16·50 17·84	do.	do.	do.	do.	do.	do.	do. do. elev. 36′	
160	VELOCITY.	25 40 26 06 26 31½ 26 55 27 21	*b* *c* *d* *e* *f*	26 25½ 23½ 26	8·65 8·82 9·57 8·65	314·1 327·0 360·6 347·2	12·69 12·94 14·04 12·69	do.	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	do.	11	11	do.	at rest. bow dep. 11′ dur. run. elev. 33′	
161	VELOCITY.	35 21½ 35 41 36 01 36 21 36 41½	*b* *c* *d* [illegible] *f*	19½ 20 20 20½	11·54 11·25 11·25 10·97	467·7 444·7 426·7 423·8	16·92 16·50 16·50 16·09	do.	do.	do.	do.	do.	do.	do. do. elev. 43′	
162	VELOCITY.	44 56 45 51 46 46 47 44½ 48 43	*b* *c* *d* *e* *f*	55 55 58½ 58½	4·09 4·09 3·84 3·84	47·0 42·1 38·4 37·5	6·00 6·00 5·64 5·64	do.	do.	very light	do.	do.	do.	do. do. level	
163	VELOCITY.	21 12½ 21 33½ 21 55 22 17 22 38	*b* *c* *d* *e* *f*	21 21½ 22 21	10·71 10·47 10·23 10·71	474·6 442·4 425·4 429·0	15·71 15·35 15·00 15·71	do.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	do.	12¼	12¼	do.	do. do. elev. 30′	
164	VELOCITY.	32 43 33 10 33 36½ 34 03½ 34 30	*b* *c* *d* *e* *f*	27 26½ 27 26½	8·33 8·49 8·33 8·49	362·6 358·4 381·0 386·7	12·22 12·45 12·22 12·45	do.	do.	do.	do.	do.	do.	do. do. elev. 43′	
165	VELOCITY.	43 54 44 44 45 37 46 30 47 22½	*b* *c* *d* *e* *f*	50 53 53 52½	4·50 4·25 4·25 4·29	63·2 57·3 51·5 55·5	6·60 6·23 6·23 6·29	do.	do.	do.	do.	do.	do.	do. do. level.	

TABLE IV. CONTINUED.—THE VELOCITY.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
166	VELOCITY.	18 22 18 46 19 09 19 31½ 19 54	*b* *c* *d* *e* *f*	24 23 22½ 22½	9·38 9·78 10·00 10·00	484·5 467·3 451·0 424·5	13·75 14·35 14·67 14·67	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	very light	13½	13½	not obs.	dur. run. bow elev. 36′	
167	VELOCITY.	28 08 28 36 29 03½ 29 32 30 00½	*b* *c* *d* *e* *f*	28 27½ 28½ 28½	8·03 8·18 7·90 7·90	386·0 376·7 387·8 412·0	11·79 12·00 11·58 11·58	do.	do.	do.	do.	do.	do.	do. do. elev. 40′	
168	VELOCITY.	39 17 40 11½ 40 05½ 41 00 41 54	*b* *c* *d* *e* *f*	54½ 54 54½ 54	4·13 4·17 4·13 4·17	53·4 50·4 57·6 54·3	6·06 6·11 6·06 6·11	do.	do.	do.	do.	do.	do.	do. do. level	
169	VELOCITY.	6 29 6 52 7 14½ 7 37 8 58	*b* *c* *d* *e* *f*	23 22½ 22½ 21	9·78 10·00 10·00 10·71	462·8 455·0 447·5 438·2	14·35 14·67 14·67 15·71	do.	do.	do.	17½	10	do.	at rest. bow dep. 43′ dur. run. elev. 28′	Weight shifted forward.
170	VELOCITY.	25 55 26 21 26 47 27 13 27 41	*b* *c* *d* *e* *f*	26 26 26 28	8·65 8·65 8·65 8·03	432·6 419·3 424·3 436·2	12·69 12·69 12·69 11·79	do.	do.	none	15½	12	do.	dur. run. bow elev. 52′	do.
171	VELOCITY.	35 42½ 36 06 36 28 36 50 37 12½	*b* *c* *d* *e* *f*	23½ 22 22 22½	9·57 10·23 10·23 10·00	488 471·2 423·6	14·04 15·00 15·00 14·67	do.	do.	do.	do.	do.	do.	do. do. elev. 29′	
172	VELOCITY.	1 32 1 55½ 2 19 2 41½ 3 40	*b* *c* *d* *e* *f*	23½ 23½ 22½ 22½	9·57 9·57 10·00 10·00	482·5 461·5 447·3 440·7	14·04 14·04 14·67 14·67	do.	do.	do.	16½	11⅝	do.	do. do. elev. 24′	Weight shifted aft.
173	VELOCITY.	30 22½ 30 48 31 12 31 38 32 07	*b* *c* *d* *e* *f*	24½ 24 26 29	9·18 9·38 8·65 7·76	504·5 489·2 481·3 485·7	13·47 13·75 12·69 11·38	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	do.	15½	15½		do. do. elev. 54′	Heavy swell.
174	VELOCITY.	41 31 42 26 43 20 44 15 45 14	*b* *c* *d* *e* *f*	55 54 55 59	4·09 4·17 4·09 3·81	51·3 53·2 55·8 46·1	6·00 6·11 6·00 5·59	do.	do.	do.	do.	do.	not obs.	do. do. level	

TABLE IV. CONTINUED.—THE VELOCITY.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
175	VELOCITY.	54 16½ 54 44 55 12½ 55 42 56 12	*b* *c* *d* *e* *f*	27½ 28½ 29½ 30	8·18 7·90 7·59 7·50	450·5 443·0 450·0 449·0	12·00 11·58 11·19 11·00	Two Horses.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	none	watr. in. 15½	watr. in. 15½	not obs.	dur. run. bow elev. 45′	
176	VELOCITY.	15 15 15 40 16 08 16 26 17 06	*b* *c* *d* *e* *f*	25 28 28 30	9·00 8·03 8·03 7·50	484·8 491·7 491·3 487·4	13·20 11·79 11·79 11·00	do.	do.	do.	20½	10		at rest, dep. 45′	Little Swell. Weight shifted forward.
177	VELOCITY.	6 10½ 6 35 7 00 7 27 7 54	*b* *c* *d* *e* *f*	24½ 25 27 27	9·18 9·00 8·33 8·33	500·4 505·6 506·0 522·0	13·47 13·20 12·22 12·22	do.	do.	do.	do.	do.	not obs.	at rest dep. 45′ during run. bow elev.	
178	VELOCITY.	22 49 23 14 23 39 24 05 24 32	*b* *c* *d* *e* *f*	25 25 26 27	9·00 9·00 8·65 8·33	489·5 492·8 504·2 512·1	13·20 13·20 12·69 12·22	do.	do.	do.	18	13	do.	do. do. bow elev. 52′	Weight shifted aft.
179	VELOCITY.	40 56 41 20 41 45 42 11½ 42 38½	*b* *c* *d* *e* *f*	26 25 26½ 27	8·65 9·00 8·49 8·33	489·2 502·0 460·0 509·0	12·69 13·20 12·45 12·22	do.	do.	do.	12¾	18	do.		do.

TABLE V.—THE EAGLE (28 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS.
											Bow	Stern			PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
180	EAGLE.	10 10 10 31 10 49 11 08½ 11 28½	*b* *c* *d* *e* *f*	21 18 19½ 20	10·71 12·50 11·54 11·25	381·6 335·5 415·6 400·0	15·71 18·33 16·92 16·50	Two Horses.	7 passengers. = *c. q. lb.* 9 2 1	none	watr. in. 18 from mrk.	watr. in. 18 from mrk.	not obs.	dur. run. bow elev. 13′	Weight of EAGLE, 3 ton. 14cwt.0qr.15lb. Towing-line fixed 15½ft. from bow. The lines of draught not being marked on this boat; the depths were therefore taken from two marks placed above the water at stem and stern.
181	EAGLE.	22 51 23 16½ 23 40½ 24 05 24 29	*b* *c* *d* *e* *f*	25½ 24 25 24	8·82 9·38 9·00 9·38	292·1 295·4 303·0 300·8	12·94 13·75 13·20 13·75	do.	do.	do.	do.	do.	do.	do. do. elev. 15′	
182	EAGLE.	34 15½ 35 10 36 05 36 59½ 37 54	*b* *c* *d* *e* *f*	54½ 55 54½ 54½	4·13 4·09 4·13 4·13	63·6 57·5 59·7 55·9	6·06 6·00 6·06 6·06	do.	do.	do.	do.	do.	do.	do. do. level	
183	EAGLE.	48 59 49 22½ 49 44 50 07½ 50 31	*b* *c* *d* *e* *f*	23½ 21½ 23½ 23½	9·57 10·47 9·57 9·57	336·3 322·8 310·4 289·3	14·04 15·35 14·04 14·04	do.	do.	do.	do.	do.	do.	do. do. elev. 10′	
184	EAGLE.	14 00½ 14 21 14 40½ 15 00 15 20½	*b* *c* *d* *e* *f*	20½ 19½ 19½ 20½	10·97 11·54 11·54 10·97	418·8 417·1 407·0 395·2	16·09 16·92 16·92 16·09	do.	7 passengers, and 1 ton. = *c. q. lb.* 29 2 1	do.	16⅛ from mrk.	16⅛ from mrk.	do.	do. do. elev. 16′	
185	EAGLE.	24 56½ 25 21 25 46 26 11 26 37	*b* *c* *d* *e* *f*	21½ 25 25 26	10·47 9·00 9·00 8·65	334·6 322·8 316·4 300·6	15·35 13·20 13·20 12·69	do.	do.	do.	do.	do.	do.	do. do. elev. 16′	
186	EAGLE.	36 02 36 54 37 46 38 39½ 39 33	*b* *c* *d* *e* *f*	52 52 53½ 53½	4·33 4·33 4·21 4·21	69·8 60·4 55·2 59·4	6·35 6·35 6·17 6·17	do.	do.	do.	do.	do.	do.	do. do. level	
187	EAGLE.	2 16 2 37 2 57 3 17½ 3 38	*b* *c* *d* *e* *f*	21 20 20½ 21½	10·71 11·25 10·97 10·47	404·3 416·7 395·5 378·3	15·71 16·50 16·09 15·35	do.	do.	do.	14 from mrk.	17½ from mrk.	do.	do do. elev. 1′	Weight shifted forward.
188	EAGLE.	21 34 21 56 22 15½ 23 35½ 23 56½	*b* *c* *d* *e* *f*	22 19½ 20 21	10·23 11·54 11·25 10·71	396·2 404·1 375·2 369·5	15·00 16·92 16·50 15·71	do.	do.	do.	17¼ from mrk.	14⅛ from mrk.	do.	do. do. elev. 38′	do. aft. Little swell.

TABLE V. continued.—THE EAGLE.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	Remarks.
											Bow	Stern			Place of experiment, Forth and Clyde Canal.
		min. sec.		sec.	miles.	lbs.	feet.								
189	Eagle.	50 50 51 12 51 32 51 53 52 14½	b c d e f	22 20 21 21½	10·23 11·25 10·71 10·47	415·8 426·8 414·5 402·0	15·00 16·50 15·71 15·35	Two Horses.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	none	watr. in. 14½ from mrk.	watr. in. 14½ from mrk.		dur. run. bow elev. 2′	Very little swell.
190	Eagle.	2 45 3 11 3 36 4 01 4 27	b c d e f	26 25 25 26	8·65 9·00 9·00 8·65	363·0 354·5 336·5 341·8	12·69 13·20 13·20 12·69	do.	do.	do.	do.	do.	near bow	do. do. elev. 16′	
191	Eagle.	18 07 18 46½ 19 25 20 06 20 46½	b c d e f	39½ 38½ 41 40½	5·69 5·84 5·49 5·56	122·1 119·8 105·1 102·2	8·35 8·57 8·05 8·15	do.	do.	do.	do.	do.	not obs.	do. do. level.	
192	Eagle.	42 38 43 00½ 43 21½ 43 42 44 04	b c d e f	22½ 21 21 22	10·00 10·71 10·71 10·23	404·2 404·2 374·0 367·1	14·67 15·71 15·71 15·00	do.	do.	do.	13⅛ from mrk.	16⅜ from mrk.		at rest. bow dep. 15′ durin run. elev. 15′	Weight shifted forward.
193	Eagle.	22 05 22 27 22 49 23 10½ 23 32	b c d e f	22 22 21½ 21½	10·23 10·23 10·47 10·47	419·7 400·0 421·8 388·0	15·00 15·00 15·35 15·35	do.	do.	do.	16⅜ from mrk.	13⅛ from mrk.	do.	at rest. bow elev. 15′ during run. 30′	do. aft.
194	Eagle.	51 28 51 50½ 52 13 52 35 52 56	b c d e f	22½ 22½ 22 21	10·00 10·00 10·23 10·71	426·4 417·8 416·7 399·7	14·67 14·67 15·00 15·71	do.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	do.	13⅝ from mrk.	13⅝ from mrk.	20 ft. from the bow.	do. do. elev. 14′	
195	Eagle.	8 31½ 8 57 9 22½ 9 48½ 10 16	b c d e f	25½ 25½ 26 27½	8·82 8·82 8·65 8·18	363·1 357·4 372·4 372·0	12·94 12·94 12·69 12·00	do.	do.	do.	do.	do.	10 ft. from the bow.	do. do. elev. 23′	
196	Eagle.	24 15 24 54 25 32½ 26 12 26 51	b c d e f	39 38½ 39½ 39	5·78 5·84 5·69 5·78	133·3 127·5 121·0 113·5	8·46 8·57 8·35 8·46	do.	do.	do.	do.	do.	none	do. do. level.	
197	Eagle.	50 31 50 54½ 51 16½ 51 38½ 52 00	b c d e f	23½ 22 22 21½	9·57 10·23 10·23 10·47	414·1 423·5 418·0 391·6	14·04 15·00 15·00 15·35	do.	do.	do.	12⅛ from mrk.	15⅛ from mrk.	not obs.	at rest. bow dep. 15′ during run. elev. 15′	Weight shifted forward.

TABLE V. continued.—THE EAGLE.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
198	Eagle.	12 57 13 21 13 44 14 06 14 27½	*b* *c* *d* *e* *f*	24 23 22 21½	9·38 9·78 10·23 10·47	415·7 411·7 413·0 400·8	13·75 14·35 15·00 15·35	Two Horses	7 passengers, and 3 ton. = *c. q. lb.* 69 2 1	none	watr. in. 15¼ from mrk.	watr. in. 12¼ from mrk.	not obs.	not obs.	Weight shifted aft.
199	Eagle.	36 59 37 23 37 45½ 38 09½ 38 32	*b* *c* *d* *e* *f*	24 22½ 24 23	9·38 10·00 9·38 9·78	441·5 446·1 423·5 424·5	13·75 14·67 13·75 14·35	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	do.	12½ from mrk.	12½ from mrk.	35ft. from the bow.	dur. run. bow elev. 21′	Towing-line at 15ft. from bow.
200	Eagle.	50 01½ 50 27½ 50 54 51 21½ 51 49½	*b* *c* *d* *e* *f*	26 27 27 28	8·65 8·33 8·33 8·03	452·6 385·7 406·8 413·0	12·69 12·22 12·22 11·79	do.	do.	do.	do.	do.	15ft. from the bow.	do. do. elev. 23′	
201	Eagle.	1 40 2 17½ 2 54 3 29½ 4 06	*b* *c* *d* *e* *f*	37½ 36½ 35½ 36½	6·00 6·16 6·34 6·16	170·5 151·4 147·4 150·5	8·80 9·04 9·30 9·04	do.	do.	do.	do.	do.	not obs.	do. do. level.	
202	Eagle.	20 23 20 47 21 12½ 21 36 22 21½	*b* *c* *d* *e* *f*	24 25½ 23½ 25½	9·38 8·82 9·57 8·82	422·8 413·3 439·3 427·3	13·75 12·94 14·04 12·94	do.	do.	do.	10¾ from mrk.	14 from mrk.	15ft. from the bow.	do. do. elev. 27′	Weight shifted foardrw.
203	Eagle.	36 39½ 37 05 37 29 37 53 38 18½	*b* *c* *d* *e* *f*	26½ 24 24 25½	8·49 9·38 9·38 8·82	429·4 439·0 442·8 432·3	12·45 13·75 13·75 12·94	do.	do.	do.	14 from mrk.	11 from mrk.	not obs.	do. do. elev. 37′	do. aft.
204	Eagle.	5 25 5 47 6 09 6 31 6 53	*b* *c* *d* *e* *f*	22 22 22 22	10·23 10·23 10·23 10·23	438·4 419·7 400·0 372·4	15·00 15·00 15·00 15·00	do.	7 passengers, and 2t.13ct.= *c. q. lb.* 62 2 1	do.	14¼ from mrk.	14¼ from mrk.	do.	do. do. elev. 17′	2 ton. 13cwt. made the Eagle, and 7 passengers, nearly equal to Zephyr, with 4 ton. 4cwt. 2 qr. and 7 passengers.
205	Eagle.	22 53 23 20 23 46 24 12 24 39	*b* *c* *d* *e* *f*	27 26 26 27	8·33 8·65 8·65 8·33	357·5 351·0 367·6 375·2	12·22 12·69 12·69 12·22	do.	do.	do.	do.	do.	do.	do. do. elev. 17′	
206	Eagle.	39 53½ 40 17 40 40 41 02½ 41 26	*b* *c* *d* *e* *f*	24½ 23 22½ 23½	9·18 9·78 10·00 9·57	395·1 407·0 411·2 385·6	13·47 14·35 14·67 14·04	do.	do.	do.	do.	do.	do.	do. do. elev. 31′	Towing-line altered from 15½ft. to within 3ft. 9in. of the bow.

TABLE V. CONTINUED.—THE EAGLE.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
207	EAGLE.	52 00 52 27½ 52 54½ 53 21 53 58	*b* *c* *d* *e* *f*	27½ 27 26½ 27	8·18 8·33 8·49 8·33	361·0 363·8 406·3 399·5	12·00 12·22 12·45 12·22	Two Horses.	7 passengers, & 2t. 13cwt. = *c. q. lb.* 62 2 1	none	watr. 14¼ from mrk.	watr. 14¼ from mrk.	not obs.	dur. run. bow elev. 37′	Towing-line 8 ft. 9 in. from bow.

TABLE VI.—THE HAWK.—(34 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
208	HAWK.	59 59½ 18 36 55 1 15½	*b* *c* *d* *e* *f*	19½ 18 19 20½	11·54 12·50 11·84 10·97	422·7 417·4 397·1 373·7	16·92 18·33 17·37 16·09	Two Horses.	7 passengers, = *c. q. lb.* 9 2 1	none	watr. in. 16⅝ from mrk.	watr. in. 18⅜ from mrk.	not obs.	dur. run. bow elev. 8′	Weight of HAWK, 3ton, 16cwt. 0q. 24lb. Marks 18½ in. above the water were made at bow and stern, when the boat was empty.
209	HAWK.	17 34 17 56½ 18 19½ 18 42 19 05½	*b* *c* *d* *e* *f*	22½ 23 22½ 23½	10·00 9·78 10·00 9·57	347·9 320·5 309·0 297·2	14·67 14·35 14·67 14·04	do.	do.	do.	do.	do.	do.	do. do. elev. 14′	
210	HAWK.	27 04½ 27 39 28 13½ 28 48 29 22½	*b* *c* *d* *e* *f*	35½ 34½ 35½ 34½	6·34 6·52 6·34 6·52	147·3 127·7 139·0 133·0	9·30 9·57 9·30 9·57	do.	do.	do.	do.	do.	do.	do. do. elev. 1′	
211	HAWK.	48 14 48 32½ 48 52 49 12 49 32	*b* *c* *d* *e* *f*	18½ 19½ 20 20	12·16 11·54 11·25 11·25	431·0 408·0 388·2 376·6	17·84 16·92 16·50 16·50	do.	7 passengers, and 7 cwt. = *c. q. lb.* 16 2 1	do.	17⅛ from mrk.	17⅛ from mrk.	do.	do. do. elev. 18′	7cwt. made the Hawk and 7 passengers nearly equal to the LARK with 1ton and 7 passengers.
212	HAWK.	58 32½ 58 56 59 19½ 59 42 05½	*b* *c* *d* *e* *f*	23½ 23½ 23 23½	9·57 9·57 9·78 9·57	340·6 323·5 302·0 302·0	14·04 14·04 14·35 14·04	do.	do.	do.	do.	do.	do.	do. do. elev. 20′	
213	HAWK.	29 23½ 29 44 30 04½ 30 25½ 30 47	*b* *c* *d* *e* *f*	20½ 20½ 21 21½	10·97 10·97 10·71 10·47	518·3 488·1 443·7 423·6	16·09 16·09 15·71 15·35	do.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	do.	12¾ from mrk.	12¾ from mrk.	do.	do. do. elev. 16′	
214	HAWK.	40 25½ 40 51½ 41 18½ 41 45½ 42 13	*b* *c* *d* *e* *f*	26 27 27 27½	8·65 8·33 8·33 8·18	427·0 395·4 430·6 448·2	12·69 12·22 12·22 12·00	do.	do.	do.	do.	do.	15ft. from the bow.	do. do. elev. 31′	
215	HAWK.	51 16½ 52 06 53 53½ 54 43½ 55 36	*b* *c* *d* *e* *f*	49½ 47½ 50 52½	4·55 4·76 4·50 4·29	75·35 57·31 64·30 64·80	6·67 6·95 6·60 6·29	do.	do.	do.	do.	do.	not obs.	do. do. level.	
216	HAWK.	12 06 12 31 12 58 13 26 13 53	*b* *c* *d* *e* *f*	25 27 28 27	9·00 8·33 8·03 8·33	427·6 408·6 421·2 445·1	13·20 12·22 11·79 12·22	do.	do.	fav. light	11 from mrk.	14 from mrk.	do.	do. do. elev. 35′	

TABLE VI. CONTINUED.—THE HAWK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
217	HAWK.	24 31½ 24 57 25 23½ 25 51 26 20½	*b* *c* *d* *e* *f*	25½ 26½ 27½ 29½	8·82 8·49 8·18 7·59	412·0 401·0 425·6 417·5	12·94 12·45 12·00 11·19	Two Horses.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	fav. light	watr. in. 14 from mrk	watr. in. 11 from mrk.	not obs.	dur. run. bow elev. 49′	Weights shifted aft.
218	HAWK.	47 23 47 45 48 06 48 27½ 48 49	*b* *c* *d* *e* *f*	22 21 21½ 21½	10·23 10·71 10·47 10·47	471·2 451·4 435·7 404·7	15·00 15·71 15·35 15·35	do.	7 passengers, & 3t. 17cwt. = *c. q. lb.* 86 2 1	do.	13 from mrk.	13 from mrk.	do.	do. do. elev. 20′	3 ton 17cwt. made the HAWK and 7 passengers nearly equal to the RAPID with 4¼ ton and 7 passengers.
219	HAWK.	58 44½ 59 10½ 59 37½ 03½ 30	*b* *c* *d* *e* *f*	26 27 26 26½	8·65 8·33 8·65 8·49	409·8 392·4 420·0 447·3	12·69 12·22 12·69 12·45	do.	do.	do.	do.	do.	do.	do. do. elev. 29′	3 ton 12cwt. made the HAWK and 7 passengers nearly equal to the LARK with 4¼ ton and 7 passengers.
220	HAWK.	34 50 35 10½ 35 31 35 52½ 36 14	*b* *c* *d* *e* *f*	20½ 20½ 21½ 21½	10·97 10·97 10·47 10·47	510·7 453·2 415·0 407·2	16·09 16·09 15·35 15·35	do.	7 passengers, & 3t. 12cwt. = *c. q. lb* 81 2 1	do.	13¼ from mrk.	13¼ from mrk.	do.	do. do. elev. 12′	
221	HAWK.	48 45 49 11 49 37 50 03 50 31	*b* *c* *d* *e* *f*	26 26 26 28	8·65 8·65 8·65 8·03	411·3 404·3 408·3 414·0	12·69 12·69 12·69 11·79	do.	do.	do.	do.	do.	do.	do. do. elev. 37′	
222	HAWK.	14 29½ 14 50 15 11 15 32½ 15 55	*b* *c* *d* *e* *f*	21½ 21 21½ 22½	10·47 10·71 10·47 10·00	465·0 420·5 397·6 369·0	15·35 15·71 15·35 14·67	do.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	do.	14 from mrk.	14 from mrk.	do.	do. do. elev. 15′	
223	HAWK.	25 19 25 43 26 08 26 33½ 27 00	*b* *c* *d* *e* *f*	26 25 25½ 26½	8·65 9·00 8·82 8·49	402·0 380·6 388·0 380·1	12·69 13·20 12·94 12·45	do.	do.	do.	do.	do.	do.	do. do. elev. 31′	
224	HAWK.	42 15½ 42 59½ 43 48 44 38 45 26½	*b* *c* *d* *e* *f*	44 48½ 50 48½	5·11 4·64 4·50 4·64	89·7 69·0 67·1 80·0	7·50 6·80 6·60 6·80	do.	do.	do.	do.	do.	do.	do. do. dep. 2′	
225	HAWK.	18 16½ 18 36 18 57 19 19½ 19 41	*b* *c* *d* *e* *f*	20½ 21 22½ 21½	10·97 10·71 10·00 10·47	 427·0 402·2 390·6	16·09 15·71 14·67 15·35	do.	7 passengers, & 2t. 12cwt. = *c. q. lb.* 61 2 1	do.	14½ from mrk.	14½ from mrk.	do.	do. do. elev. 15′	2 ton 12cwt. made the HAWK and 7 passengers nearly equal to the RAPID with 3 ton and 7 passengers.

TABLE VI. CONTINUED.—THE HAWK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
226	HAWK.	28 58 29 23 29 49 30 $14\frac{1}{2}$ 30 $40\frac{1}{2}$	*b* *c* *d* *e* *f*	25 26 $25\frac{1}{2}$ 26	9·00 8·65 8·82 8·65	405·5 384·7 386·0 390·6	13·20 12·69 12·94 12·69	Two Horses.	7 passengers & 2 t. 12 cwt. = *c. q. lb.* 61 2 1	fav. light	watr. in. $14\frac{1}{2}$ from mrk.	watr. in. $14\frac{1}{2}$ from mrk.	not obs.	dur. run. bow elev. 30′	
227	HAWK.	42 $11\frac{1}{2}$ 42 $32\frac{1}{2}$ 42 $54\frac{1}{2}$ 43 16 43 37	*b* *c* *d* *e* *f*	21 22 $21\frac{1}{2}$ 21	10·71 10·23 10·47 10·71	457·7 406·1 412·5 389·2	15·71 15·00 15·35 15·71	do.	do.	do.	do.	do.	do.	do. do. elev. 12′	
228	HAWK.	1 23 1 45 2 06 2 $27\frac{1}{2}$ 3 $18\frac{1}{2}$	*b* *c* *d* *e* *f*	22 21 $21\frac{1}{2}$ 21	10·23 10·71 10·47 10·71	461·6 397·5 403·3 390·3	15·00 15·71 15·35 15·71	do.	7 passengers & 2 t. 7 cwt. = *c. q. lb.* 56 2 1	fav.	$14\frac{3}{4}$ from mrk.	$14\frac{3}{4}$ from mrk.	do.	do. do. elev. 13′	2 ton 7 cwt. made the HAWK and 7 passengers nearly equal to the LARK, with 3 ton and 7 passengers.
229	HAWK.	19 $30\frac{1}{2}$ 19 55 20 20 20 45 20 $10\frac{1}{2}$	*b* *c* *d* *e* *f*	$25\frac{1}{2}$ 25 25 $25\frac{1}{2}$	8·82 9·00 9·00 8·82	401·8 380·7 387·1 384·5	12·94 13·20 13·20 12·94	do.	do.	do.	do.	do.	do.	do. do. elev. 31′	
230	HAWK.	47 32 47 53 48 14 48 35 48 57	*b* *c* *d* *e* *f*	21 21 21 22	10·71 10·71 10·71 10·23	454·4 407·2 382·5 372·6	15·71 15·71 15·71 15·00	do.	7 passengers and 2 ton, = *c. q. lb.* 49 2 1	do.	15 from mrk.	15 from mrk.	do.	do. do. elev. 14′	
231	HAWK.	51 $42\frac{1}{2}$ 52 08 52 33 52 59 53 24	*b* *c* *d* *e* *f*	$25\frac{1}{2}$ 25 26 25	8·82 9·00 8·65 9·00	393·0 358·8 367·4 379·7	12·94 13·20 12·69 13·20	do.	do.	do.	do.	do.	do.	do. do. elev. 34′	
232	HAWK.	5 $57\frac{1}{2}$ 6 46 7 $38\frac{1}{2}$ 8 31 9 $21\frac{1}{2}$	*b* *c* *d* *e* *f*	$48\frac{1}{2}$ $52\frac{1}{2}$ $52\frac{1}{2}$ $50\frac{1}{2}$	4·64 4·29 4·29 4·46	74·6 66·0 60·7 58·1	6·80 6·29 6·29 6·53	do.	do.	do.	do.	do.	do.	do. do. level	
233	HAWK.	23 $19\frac{1}{2}$ 23 44 24 $08\frac{1}{2}$ 24 30 24 56	*b* *c* *d* *e* *f*	$25\frac{1}{2}$ $24\frac{1}{2}$ $23\frac{1}{2}$ 24	8·82 9·18 9·57 9·38	397·9 373·3 382·3 369·4	12·94 13·47 14·04 13·75	do.	do.	do.	$13\frac{1}{4}$ from mrk.	$16\frac{3}{8}$ from mrk.	do.	at rest. dep. dur. run. elev. 29′	Weight shifted forward.
234	HAWK.	50 48 51 12 51 38 52 $02\frac{1}{2}$ 52 26	*b* *c* *d* *e* *f*	24 26 $24\frac{1}{2}$ $23\frac{1}{2}$	9·38 8·65 9·18 9·57	367·8 359·1 390·9 395·7	13·75 12·69 13·47 14·04	do.	do.	fav. light	$16\frac{1}{2}$ from mrk.	$13\frac{1}{2}$ from mrk.	do.	do. do. elev. 42′	Weight shifted aft.

TABLE VI. CONTINUED.—THE HAWK.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
235	HAWK.	49 57 50 21 50 46 51 09½ 51 32½	*b* *c* *d* *e* *f*	24 25 23½ 23	9·38 9·00 9·57 9·78	400 374·5 383 390	13·75 13·20 14·04 14·35	Two Horses.	7 passengers, and 2 ton, = *c. q. lb.* 49 2 1	fav. very light	watr. in. 18⅛ from mrk.	watr. in. 11⅝ from mrk.	not obs.	bow elev. at rest. 30′ during run. 57′	Weights shifted.
236	HAWK.	28 24 28 44 29 05 29 26 29 47	*b* *c* *d* *e* *f*	20 19 21 21	11·25 11·84 10·71 10·71	446·6 396·2 386·3 374·5	16·50 17·37 15·71 15·71	do.	7 passengers, & 1t. 12cwt. = *c. q. lb.* 41 2 1	do.	15⅜ from mrk.	15⅜ from mrk.	do.	do. do. elev. 15′	HAWK, with 7 passengers, 1 ton, 12cwt., nearly equal to RAPID, with 2 ton and 7 passengers.
237	HAWK.	41 04 41 28 41 53 42 16½ 42 40	*b* *c* *d* *e* *f*	24½ 24½ 23½ 22½	9·18 9·18 9·57 10·00	379·3 362·5 374·3 360·4	13·47 13·47 14·04 14·67	do.	do.	do.	do.	do.	do.	do. do. elev. 25′	do.
238	HAWK.	54 42½ 55 03 55 23 55 44 56 06	*b* *c* *d* *e* *f*	20½ 20 21 22	10·97 11·25 10·71 10·23	456·6 406·2 380 372·6	16·09 16·50 15·71 15·00	do.	7 passengers, &1 t. 5 cwt. = *c. q. lb.* 34 2 1	do.	15¾ from mrk.	15¾ from mrk.	do.	do. do. elev. 14′	HAWK, with 7 passengers and 1 ton, 5cwt., nearly equal to LARK, with 1 ton, 18cwt. 7 passengers, and to ZEPHYR, with 3 ton, 7 passengers.
239	HAWK.	4 38 5 02½ 5 27½ 5 51½ 6 15½	*b* *c* *d* *e* *f*	24½ 25 24 24	9·18 9·00 9·38 9·38	369·4 348·5 356·6 357·5	13·47 13·20 13·75 13·75	do.	do.	do.	do.	do.	do.	do. do. elev. 34′	
240	HAWK.	21 50½ 22 10 22 30½ 22 50½ 23 12½	*b* *c* *d* *e* *f*	19½ 20½ 20 22½	11·54 10·97 11·25 10·00	450·6 381·7 375·2 363·3	16·92 16·09 16·50 14·67	do.	7 passengers, and 12 cwt. = *c. q. lb.* 21 2 1	do.	11¾ from mrk.	11¾ from mrk.	do.	do. do. elev. 6′	HAWK, with 7 passengers and 12cwt., nearly equal to the RAPID, with 1 ton and 7 passengers.
241	HAWK.	31 40½ 32 04 32 27 33 50 34 14	*b* *c* *d* *e* *f*	23½ 23 23 24	9·57 9·78 9·78 9·38	366·9 343·1 341·3 318·5	14·04 14·35 14·35 13·75	do.	do.	do.	do.	do.	do.	do. do. elev. 12′	

TABLE VII.—THE RAPID (SECOND SET—43 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
242	RAPID.	41 20 41 51½ 42 23 42 55 43 28	*b* *c* *d* *e* *f*	31½ 31½ 32 33	7·14 7·14 7·03 6·82	338·7 322·1 328·1 273·7	10·48 10·48 10·31 10·00	Two Horses.	7 passengers, and 4¼ ton, = *c. q. lb.* 94 2 1	unf. strng	in. 16	in. 16	not obs.	dur. run. bow elev. 17′	RAPID weighed when empty, 3 ton, 8cwt. 2qr. 20lb.
243	RAPID.	53 19 53 45 54 13 54 43 55 15	*b* *c* *d* *e* *f*	26 28 30 32	8·65 8·03 7·50 7·03	496·4 483·5 492 412·7	12·69 11·79 11·00 10·31	do.	do.	do.	do.	do.	do.	do. do. elev. 40′	A Passage-boat passed at 5 sec.
244	RAPID.	5 54 6 20 6 48 7 17½ 7 47	*b* *c* *d* *e* *f*	26 28 29½ 29½	8·65 8·03 7·59 7·59	499·5 477·8 477·5 473·5	12·69 11·79 11·19 11·19	do.	do.	do.	do.	do.	do.	do. do. elev. 48′	
245	RAPID.	37 51 38 18 38 46 39 15½ 39 45	*b* *c* *d* *e* *f*	27 28 29½ 29½	8·33 8·03 7·59 7·59	483·8 477·5 547·8 477·2	12·22 11·79 11·19 11·19	do.	7 passengers, and 4 ton, = *c. q. lb.* 89 2 1	do.	16	16¼	do.	do. do. elev. 40′	RAPID, with 7 passengers and 4 ton, nearly equal to the LARK, with 4¼ ton and 7 passengers.
246	RAPID.	35 13½ 35 47 36 09 36 40 37 11	*b* *c* *d* *e* *f*	33½ 32 31 31	6·72 7·03 7·26 7·26	488·8 470 466 428	9.85 10.31 10.65 10.65	do.	do.	do.	do.	do.	do.	do. do. elev. 25′	
247	RAPID.	11 51 12 16½ 12 42½ 13 10 13 38	*b* *c* *d* *e* *f*	25½ 26 27½ 28	8·82 8·65 8·18 8·03	456 442·8 455 467·2	12·94 12·69 12·00 11·79	do.	do.	fav.	do.	do.	do.	do. do. elev. 1° 6′	
248	RAPID.	49 32½ 49 56½ 50 21½ 50 45½ 51 10½	*b* *c* *d* *e* *f*	24 25 24 25	9·38 9·00 9·38 9·00	447·1 447·5 429·6 360·6	13·75 13·20 13·75 13·20	do.	do.	do.	15⅛	15⅛	do.	do. do. elev. 50′	RAPID, with 7 passengers, 3 ton, and 7cwt., nearly equal to the VELOCITY, HAWK, and EAGLE, with 3 ton and 7 passengers each.
249	RAPID.	4 07 4 34½ 5 02 5 29 5 57	*b* *c* *d* *e* *f*	27½ 27½ 27 28	8·18 8·18 8·33 8·03	419·3 411·4 452·8 453	12·00 12·00 12·22 11·79	do.	do.	light	do.	do.	do.	do. do. elev. 58′	
250	RAPID.	21 58 22 22 22 44½ 23 07½ 23 31	*b* *c* *d* *e* *f*	24 22½ 23 23½	9·38 10·00 9·78 9·57	480·5 436·4 413·5 370	13·75 14·67 14·35 14·04	do.	7 passengers, & 2t. 15cwt. = *c. q. lb.* 61 2 1	do.	14⅛	14⅛	do.	do. do. elev. 10′	RAPID, with 7 passengers and 2 ton 15cwt., nearly equal to the LARK, with 3 ton and 7 passengers.

TABLE VII. CONTINUED.—THE RAPID (SECOND SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P.
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow.	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
251	RAPID.	33 14½ 33 41 34 08½ 34 36 35 04½	*b* *c* *d* *e* *f*	26½ 27½ 27½ 28½	8·49 8·18 8·18 7·90	406·8 390 400 417·5	12·45 12·00 12·00 11·58	Two Horses.	7 passengers, & 2t. 15 cwt. = *c. q. lb.* 64 2 1	fav. light	14⅛	14⅛	not obs.	dur. run. bow elev. 35′	
252	RAPID.	57 41 58 04 58 26 58 47½ 59 09½	*b* *c* *d* *e* *f*	23 22 21½ 22	9·78 10·23 10·47 10·23	450 420 419 406	14·35 15·00 15·35 15·00	do.	7 passengers, & 2t. 7 cwt = *c. q. lb.* 56 2 1	none	13⅝	13⅝	do.	do. do. elev. 38′	RAPID, with 7 passengers and 2 ton 7cwt., nearly equal to the EAGLE, VELOCITY, and HAWK, with 2 ton and 7 passengers each.
253	RAPID.	6 58 7 23½ 7 50 8 15½ 8 42	*b* *c* *d* *e* *f*	25½ 26½ 25½ 26½	8·82 8·49 8·82 8·49	401 372 407 397	12·94 12·45 12·94 12·45	do.	do.	do.	do.	do.	do.	do. do. elev. 48′	
254	RAPID.	21 07½ 21 29½ 21 41½ 22 13 22 35	*b* *c* *d* *e* *f*	23 23 21½ 23	10·23 10·23 10·47 10·23	440 400 400 382·5	15·00 15.00 15·35 15·00	do.	7 passengers, & 1t. 15 cwt. = *c. q. lb.* 44 2 1	do.	12¾	12⅝	do.	do. do. elev. 8′	RAPID, with 7 passengers, 1 ton 15cwt., nearly equal to the LARK, with 2 ton and 7 passengers, and ZEPHYR, with 3 ton and 7 passengers.
255	RAPID.	30 46 31 12 31 38½ 32 05½ 32 32½	*b* *c* *d* *e* *f*	26 26½ 27 27	8·65 8·49 8·33 8·33	360 361·6 352·2 358·8	12·69 12·45 12·22 12·22	do.	do.	do.	do.	do.	do.	do. do. elev. 35′	
256	RAPID.	24 45 1 06 1 28 1 50½	*b* *c* *d* *e* *f*	21 21 22 22½	10·71 10·71 10·23 10·00	461 412·8 376 352	15·71 15·71 15·00 14·67	do.	7 passengers, & 1t. 7 cwt. = *c. q. lb.* 36 2 1	do.	12	11¾	do.	do. do. elev. 18′	RAPID, with 7 passengers, and 1 ton 7cwt., nearly equal to the VELOCITY, EAGLE, and HAWK, with 1 ton and 7 passengers each.
257	RAPID.	18 06 18 35 19 02 19 28 19 57	*b* *c* *d* *e* *f*	29 27 26 29	7·76 8·33 8·65 7·76	289 308 346 323·7	11·38 12·22 12·69 11·38	do.	do.	do.	do.	do.	do.	do. do. elev. 42′	
258	RAPID.	26 05½ 26 27 26 50 27 12 27 34	*b* *c* *d* *e* *f*	21½ 23 22 22	10·47 9·78 10·23 10·23	374 351 350 325	15·35 14·35 15.00 15·00	do.	7 passengers, and 15 cwt. = *c. q. lb.* 24 2 1	do.	do.	do.	do.	not obs.	RAPID, with 7 passengers and 15cwt., nearly equal to the LARK, with 1 ton and 7 passengers, and to the ZEPHYR, with 2 ton and 7 passengers.
259	RAPID.	35 35 36 04 36 30 36 57 37 25	*b* *c* *d* *e* *f*	29 26 27 28	7·76 8·65 8·33 8·03	302·8 308·5 306·2 302·2	11·38 12·69 12·22 11·79	do.	do.	do.	do.	do.	do.	not obs.	

TABLE VII. continued.—THE RAPID (Second Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, MONKLAND CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
		11 42	*b*	32	7·03	320	10·31								
260	Rapid.	12 14	*c*	35	6·43	326	9·43	Two Horses	7 passengers, and 1 ton, = *c. q. lb.* 29 2 1	none	in. $11\frac{1}{4}$	in. $11\frac{1}{4}$	20 yards before the boat.	dur. run. bow elev. 1° 0′	
		12 49	*d*												
		18 39	*b*	20	11·25	425	16·50								
261	Rapid.	18 59	*c*	21	10·71	387	15·71	do.	do.	do.	do.	do.	just astern	do. do. elev. 10′	
		19 20	*d*												
		27 13	*b*	$20\frac{1}{2}$	10·97	391	16·09								
262	Rapid.	27 $33\frac{1}{2}$	*c*	$20\frac{1}{2}$	10·97	375	16·09	do.	do.	do.	do.	do.	do.	do. do. elev. 10′	
		27 54	*d*												
		33 34	*b*	25	9·00	366	13·20								
263	Rapid.	33 59	*c*	23	9·78	349	14·35	do.	do.	do.	do.	do.	about the mddle of the boat.	do. do. elev. 6′	
		34 22	*d*												
		40 27	*b*	37	6·08	172	8·92								
264	Rapid.	41 04	*c*	36	6·25	164	9·17	do.	do.	do.	do.	do.	about 12ft. from the bow.	do. do. elev. 9′	
		41 40	*d*												
		49 53	*b*	32	7·03	324	10·31								
265	Rapid.	50 25	*c*	34	6·62	345	9·71	do.	do.	do.	do.	do.	about the bows, and a heavy wave after the boat.	do. do. elev. 1° 1′	
		50 59	*d*												
		59 $17\frac{1}{2}$	*b*	59	3·81	48	5·59								
266	Rapid.	$16\frac{1}{2}$	*c*	$62\frac{1}{2}$	3·60	36	5·28	do.	do.	do.	do.	do.		do. do. level.	
		1 19	*d*												
		7 2	*b*	37	6·08	145	8·92								
267	Rapid.	7 39	*c*	38	5·92	125	8·68	do.	do.	do.	do.	do.	about the quartr	do. do. elev. 15′	
		8 17	*d*												
		21 $10\frac{1}{2}$	*b*	21	10·71	406	15·71								
268	Rapid.	21 $31\frac{1}{2}$	*c*	$21\frac{1}{2}$	10·47	342	15·35	do.	do.	do.	$14\frac{1}{2}$	$9\frac{1}{2}$	at the mddle of the boat.	do. do. level.	Shifted the weights to the bow.
		21 53	*d*												

TABLE VII. continued.—THE RAPID (Second Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, MONKLAND CANAL.
											Bow	Stern			
		min. sec.		sec.	miles.	lbs.	feet.				in.	in.			
269	Rapid.	28 28½	b	28½	7·90	364·7	11·58	Two Horses.	7 passengers, and 1 ton, = c. q. lb. 29 2 1	none	14½	9½	just at the bow.	dur. run. bow elev. 25′	Heavy swell.
		28 57	c	28	8·03	385	11·79								
		29 25	d												
270	Rapid.	36 59	b	25	9·00	318	13·20	do.	do.	do.	do.	do.	15 feet farther aft.	do. do. elev. 15′	Swell not so heavy.
		37 24	c	24	9·38	259	13·75								
		37 48	d												
271	Rapid.	50 51½	b	31	7.26	362·7	10·65	do.	do.	do.	do.	do.	about 20 yds before the boat.	do. do. elev. 54′	
		51 22½	c	30½	7·38	431	10·82								
		51 53	d												
272	Rapid.	58 38	b	33	6·82	313·5	10·00	do.	do.	do.	do.	do.	a little before the boat.	do. do. elev. 43′	
		59 11	c	33	6·82	346	10·00								
		59 44	d												
273	Rapid.	6 54	b	48	4·69	82	6·88	do.	do.	do.	do.	do.	after the boat.	do. do. dep. 12′	Swell very slight.
		7 42	c	48½	4·64	78	6·80								
		8 30½	d												
274	Rapid.	14 3	b	21	10·71	395	15·71	do.	do.	do.	do.	do.	in mid-ships.	do. do. dep. 5′	
		14 24	c	21	10·71	348	15·71								
		14 45	d												
275	Rapid.	23 20	b	24	9·38	322	13·75	do.	do.	do.	do.	do.	about 18 feet from the bow.	do. do. elev. 22′	
		23 44	c	23½	9·57	271	14·04								
		24 7½	d												
276	Rapid.	45 20	b	28	8·03	373	11·79	do.	do.	do.	9	14	at the bow.	do. do. elev. 1°17′	Weight shifted to stern; swell very high, rose 3 feet.
		45 48	c	26½	8·49	389·6	12·45								
		46 14½	d												
277	Rapid.	54 10	b	20½	10·97	375	16·09	do.	do.	do.	do.	do.	at mid-ships.	do. do. elev. 27′	Not so high.
		54 30½	c	20½	10·97	370·6	16·09								
		54 51	d												

TABLE VII. continued.—THE RAPID (Second Set).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, MONKLAND CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
278	Rapid.	3 53	b	33	6·82	324·6	10·00	Two Horses	7 passengers, and 1 ton, = c. q. lb. 29 2 1	none	in. 9	in. 14	30 yds. before the boat, broken water behind the boat.	dur. run. bow elev. 1°18′	
		4 26	c	33	6·82	350	10·00								
		4 59	d												
279	Rapid.	12 58	b	54	4·17	60	6·11	do.	do.	do.	do.	do.		do. do. elev. 17′	Very little swell.
		13 52	c	51	4·41	58·7	6·47								
		14 43	d												
280	Rapid.	30½	b	25½	8·82	368	12·94	do.	do.	do.	do.	do.	at mid-ships	do. do. elev. 42′	
		56	c	26	8·65	340·6	12·69								
		1 22	d												
281	Rapid.	16 52	b	23½	9·57	383·5	14·04	do.	8 passengers, and 1 ton, = c. q. lb 11 3 3	do.	not obs.	not obs.		not obs.	
		17 15½	c	22½	10·00	328	14·67								
		17 38	d												
282	Rapid.	31 55	b	20	11·25	366	16·50	do.	8 passengers, = c. q. lb. 10 3 3	do.	11	8¾		dur. run. bow level	
		32 15	c	20	11·25	347	16·50								
		32 35	d												
283	Rapid.	40 38	b	25½	8·82	319·7	12·94	do.	do.	do.	do.	do.		do. do. elev. 45′	
		41 03½	c	26½	8·49	366·5	12·45								
		41 30	d												
284	Rapid.	00	b	22½	10·00	301	14·67	do.	do.	do.	do.	do.		do. do. elev. 2′	Very little swell.
		22½	c	22½	10·00	278·6	14·67								
		1 45	d												
285	Rapid.	9 24½	b	50½	4·46	61	6·53	do.	do.	do.	do.	do.			
		10 15	c	51½	4·37	67	6·41								
		11 06½	d												

TABLE VIII.—NEW BOAT (14 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
286	NEW BOAT.	4 28 4 53 5 18 5 41 6 05	*b* *c* *d* *e* *f*	25 25 23 24	9·00 9·00 9·78 9·38	206·5 185 202·8 223·5	13·20 13·20 14·35 13·75	Two Horses.	6 passengers, and 1 ton, = *c. q. lb.* 28 0 15	none	not obs.	not obs.	not obs.	not obs.	Experiments on Keels of different forms. Keel 30ft. long, 6in. deep, tapered off to a point at 4ft. from the ends. Boat 61ft. 6in. long.
287	NEW BOAT.	26 28½ 26 47½ 27 06 27 25 27 44	*b* *c* *d* *e* *f*	19 18½ 19 19	11·84 12·16 11·84 11·84	307 299 290·8 267·8	17.37 17.84 17.37 17.37	do.	do.	do.	do.	do.	do.	do.	Heavy rain.
288	NEW BOAT.	35 40 36 15 36 51 37 27 38 03½	*b* *c* *d* *e* *f*	35 36 36 36½	6·43 6·25 6·25 6·16	96·8 86·6 84 81·7	9·43 9·17 9·17 9·04	do.	do.	unf. strng	do.	do.	do.	do.	
289	NEW BOAT.	48 32½ 48 58 49 23½ 49 47½ 50 12½	*b* *c* *d* *e* *f*	25½ 25½ 24 25	8·82 8·82 9·38 9·00	193·8 202·5 190·7 186·6	12·94 12·94 13·75 13·20	do.	do.	do.	do.	do.	do.	do.	
290	NEW BOAT.	46 25 46 54 47 22½ 47 50 48 19½	*b* *c* *d* *e* *f*	29 28½ 27½ 28½	7·76 7·90 8·18 7·90	164·5 163 178·8 151·6	11·38 11·58 12·00 11·58	do.	do.	do.	in. 24	in. 21⅛	do.	do.	Triangular Keel 20ft. long, 7in. deep.
291	NEW BOAT.	55 45 56 10 56 33½ 57 57 58 21	*b* *c* *d* *e* *f*	25 23½ 23½ 24	9·00 9·57 9·57 9·38	180·6 203·7 209 191	13·20 14·04 14·04 13·75	do.	do.	do.	do.	do.	do.	do.	
292	NEW BOAT.	2 38 2 54 3 11 3 28½ 3 46½	*b* *c* *d* *e* *f*	16 17 17½ 18	14·06 13·24 12·86 12·50	339 346·6 318 303	20·63 19·41 18·86 18·33	do.	do.	do.	do.	do.	do.	do.	
293	NEW BOAT.	17 18½ 17 37 17 57 18 17 18 37	*b* *c* *d* *e* *f*	18½ 20 20 20	12·16 11·25 11·25 11·25	316·6 288 273 277·5	17·84 16·50 16·50 16·50	do.	do.	not so strng	do.	do.	do.	do.	Keel 20ft. long, 10in. deep in the middle, curved to both ends.
294	NEW BOAT.	29 40 30 05 30 29 30 54 31 18	*b* *c* *d* *e* *f*	25 24 25 24	9·00 9·38 9·00 9·38	203·5 192·8 192·5 196·8	13·20 13·75 13·20 13·75	do.	do.	do.	do.	do.	do.	do.	

TABLE VIII. CONTINUED.—NEW BOAT.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
		min. sec.		sec.	miles.	lbs.	feet.								
295	NEW BOAT.	39 15½ 40 08 41 01 41 55 42 49	*b* *c* *d* [illegible] *f*	52½ 53 54 54	4·29 4·25 4·17 4·17	50 49 47·7 48	6·29 6·23 6·11 6·11	Two Horses.	6 passengers, and 1 ton, = *c. q. lb.* 28 0 15	unf. not so strng	in. 24	in. 21⅛	not obs.	not obs.	Very little swell.
296	NEW BOAT.	20 48 21 07 21 27 21 46½ 22 06	*b* *c* *d* *e* *f*	19 20 19½ 19½	11·84 11·25 11·54 11·54	298 276 261 267	17·37 16·50 16·92 16·92	do.	do.	do.	23	21⅜	do.	do.	Keel 10 feet long, 14 in. deep in the middle, being the segment of a circle, the middle of which was 27 feet from the middle of boat forward.
297	NEW BOAT.	27 33½ 27 57 28 21 28 44 29 07	*b* *c* *d* *e* *f*	23½ 24 23 23	9·57 9·38 9·78 9·78	207 214 221 200·7	14·04 13·75 14·35 14·35	do.	do.	do.	do.	do.	do.	do.	
298	NEW BOAT.	37 11 37 51½ 38 28 39 06½ 39 45	*b* *c* *d* *e* *f*	40½ 36½ 38½ 38½	5·56 6·16 5·84 5·84	73 88 71·8 78·5	8·15 9·04 8·57 8·57	do.	do.	do.	do.	do.	do.	do.	

TABLE IX.—THE SWIFT (First Set—11 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught. Bow	Draught. Stern	Position of Wave.	Variation in Level.	Remarks. PLACE OF EXPERIMENT, GLASGOW AND PAISLEY CANAL
		min. sec.		sec.	miles.	lbs.	feet.								
299	Swift.	21 25	*b*	24	9·38	233·3	13·75	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	light	in. 13½	in. 13¾		dur. run. bow elev. 4′	
		21 49	*c*	24	9·38	230·6	13·75								
		22 13	*d*												
300	Swift.	33 30½	*b*	16	14·06	521·7	20·63	do.	do.	do.	do.	do.	17ft. from stern on larboard side.	do. do. elev. 6′	Boat one-third the width of the canal from the towing-path.
		33 46½	*c*	17½	12·86	475	18·86								
		34 04	*d*												
301	Swift.	39	*b*	20	11·25	358	16·50	do.	do.	do.	do.	do.	more frwrd than last expe-rimnt.	do. do. elev. 8′	
		59	*c*	20	11·25	344	16·50								
		1 19	*d*												
302	Swift.	51 14½	*b*	24½	9·18	250	13·47	do.	do.	do.	do.	do.	at mid-ships.	do. do. elev. 5′	Horses did not go steady.
		51 39	*c*	24	9·38	221	13·75								
		52 03	*d*												
303	Swift.	4 40	*b*	24	9·38	272	13·75	do.	do.	do.	do.	do.		do. do. dep. 5′	
		5 04	*c*	26	8·65	222	12·69								
		5 30	*d*												
304	Swift.	13 36	*b*	25	9·00	268	13·20	do.	do.	do.	do.	do.	about ¼ from bow.	do. do. elev. 29′	Not a good experiment.
		14 01	*c*	26½	8·49	161	12·45								
		14 27½	*d*												
305	Swift.	21 47	*b*	33	6·82	360	10·00	do.	do.	do.	do.	do.	40 yards a head of boat.	do. do. elev. 1°7′	
		22 20	*c*	33	6·82	371	10·00								
		22 53	*d*												
306	Swift.	29 56	*b*	41	5·49	268·8	8·05	do.	do.	do.	do.	do.		do. do. elev. 58′	
		30 37	*c*	41½	5·42	347·7	7·95								
		31 17½	*d*												
307	Swift.	38 50½	*b*	47	4·79	91·2	7·02	do.	do.	do.	do.	do.		do. do. elev. 3′	
		39 37½	*c*	47½	4·76	76·6	6·95								
		40 25	*d*												

TABLE IX. CONTINUED.—THE SWIFT (FIRST SET).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, GLASGOW AND PAISLEY CANAL.
											Bow	Stern			
		min. sec.		sec.	miles.	lbs.	feet.								
308	SWIFT.	44½ 1 12½ 1 39	*b* *c* *d*	28 26½	8·03 8·49	266·6 358·8	11·79 12·45	Two Horses.	7 passengers, and 3 ton, = *c. q. lb.* 69 2 1	light	in. 13½	in. 13¾		dur. run. bow elev. 1°20′	
309	SWIFT.	52 15 52 49 53 23	*b* *c* *d*	34 34	6·62 6·62	341·8 335·5	9·71 9·71	do.	9 passengers, and 2t.15ct.= *c. q. lb.* 67 0 25	do.					

TABLE X.—ZEPHYR AND RAPID LASHED TOGETHER (2 *Experiments*).

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
No. of Experiment.	Boat's Name.	Instant of passing the Stake.	Stakes 110 yards apart.	Time of passing the Stake-interval.	Miles per Hour.	Tractive Power in lbs.	Feet per Second.	Kind of Tractive Power.	Load.	Wind.	Draught.		Position of Wave.	Variation in Level.	REMARKS. PLACE OF EXPERIMENT, FORTH AND CLYDE CANAL.
											Bow	Stern			
		min. sec.		sec.	miles.	lbs.	feet.								
310	ZEPHYR AND RAPID lashed together.	53 20 53 54 54 28 55 03½ 55 40	*b* *c* *d* *e* *f*	34 34 35½ 36½	6·62 6·62 6·34 6·16	297·5 264·4 231 201·5	9·71 9·71 9·30 9·04	Two Horses.	7 passengers, = *c. q. lb.* 9 2 1	not obs.	in. 7	in. 6	not obs.	not obs.	
311	ZEPHYR AND RAPID lashed together.	21 46 22 07 22 28 22 52½ 23 17	*b* *c* *d* *e* *f*	21 21 24½ 24½	10·71 10·71 9·18 9·18	 472 521·8	15·71 15·71 13·47 13·47	Three Horses.	do.	do.	do.	do.	do.	do.	In this experiment the pull went above the range of the Dynamometer in the first two stake-intervals.

TABLE XI.—THE SWIFT (Second Set).

ACTUAL TRACTIVE POWER OBSERVED IN WORKING THE SWIFT EIGHT MILES ALONG THE GLASGOW AND PAISLEY CANAL, AT THE ORDINARY PASSENGER-SPEED, OR NINE MILES PER HOUR.

Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.
170	Load—Eleven passengers and 2 ton. 15cwt., equal to 69 cwt. 3 qr. 20 lb. from Half-way House to Glasgow, and one passenger additional from the Culvert to Glasgow.	225		350		240	pass Bridge.
400		215		240		310	
400		210		300		260	
280		225		305		235	
260		195		270		245	
265		220		235		240	pass Course—Place where the Experiments were made.
240		285	pass Bridge.	230		230	
230	pass Mile-stone.	270		235		215	
240		230		240		215	
230		220		235		240	
220		235	pass Mile-stone.	225		210	
210		230		225		200	
205		235		240		235	
210		245		230		200	
215		270		260	Barge passes.	120	pass Aqueduct.
215		260		250		120	
210		230		275	turn.	150	
220		205		250		150	
245	turn corner.	215		230	pass Mile-stone.	130	
235		235		230		120	
265		235		210		100	
245		300	pass Narrow Bridge.	215		110	
205		360		235		110	
220		350		235		110	
200		300		225		100	
200		240		215		90	
195		290		215		100	Port Eglinton.
190	stop and take in a passenger. Load, therefore, about 71 cwt.	320		215			
390		300	A Boat passed.	230			
425	go on again.	270		240			
380		320		235			
230		250		270			
220		340	pass Bridge. Bad turn.	260			

TABLE XII.—THE ZEPHYR (Second Set).

ACTUAL TRACTIVE POWER OBSERVED IN WORKING THE ZEPHYR EIGHT MILES ALONG THE FORTH AND CLYDE CANAL, AT THE ORDINARY PASSENGER-SPEED, OR NINE MILES PER HOUR.

Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.	Tractive Power in lbs.	REMARKS.
395		370		405		315	
395	Load—Nine passengers and 3 ton, equal to 72 cwt. 0qr. 25lb.	375		395		305	
395		350		340		300	
400		250		190	stopped by a Vessel at Bridge.	310	
415		240		70		295	
445		285	turn.	0		300	turn.
555		320		0		325	
460		325		0		325	
190	pass Bridge.	350		0	pass Bridge.	325	
20	take off Rope.	420		170		340	
20		425		330		300	
20		420		380		310	pass Culvert.
300		260	pass Bridge.	385		270	turn.
310		0		385		310	
310		0		390		370	
100	pass Barge.	0	pass Mile-stone.	380		355	
0		440		385		385	
0		445		370		360	
0		395		370		280	
80		385		370	pass Mile-stone.	265	turn.
300		365		335		245	
355		380		330		300	
395		380		270		370	
420		385		160	pass Stockingfield Bridge.	360	
425		360		150	stop.	310	
425		350		0		320	pass Mile-stone.
410		355		0		345	
405		330		0	start again.	360	
405		325		130		390	
405		350		310		390	
375		320		355		390	
355		345		355		400	
355		340		345		400	
345		290	turn.	340		400	
320		200		315		370	Lamb-hill Bridge.
320		230		320		140	
330		250					

APPENDIX.

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1836.

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HOPKINS, THOMAS, Plymouth and Bath.
IRVINE, Major ARCHIBALD, Bengal Engineers, Calcutta.
JONES, R. W., Langhor, near Swansea, Glamorganshire.
KNIGHT, PATRICK, Castlebar, Ireland.
LAGERHEIM, Captain GUSTAFF, Gotha Canal, Sweden.
LEATHER, GEORGE, Leeds.
LESLIE, JAMES, Dundee.
LIPKINS, ANTOINE, The Hague, Holland.
LOCKE, JOSEPH, Liverpool.
LOGAN, DAVID, Glasgow.
MACKENZIE, WILLIAM, Liverpool.
MAY, GEORGE, Clackmacarry, Inverness.
MILLER, JOHN, Edinburgh.

Moses, Moses, Newport, Monmouthshire.
Murray, John, Sunderland.
Manby, Aaron, Creuzot, Sâone et Loire, France.
Neilson, James B., Glasgow.
Newnham, Thomas G., Newtown, Montgomeryshire.
Oldham, James, Hull.
Parkes, Josiah, Cork.
Peel, George, Soho, Manchester.
Potter, James, Birmingham.
Price, Henry H., F.G.S., M.R.I.A., Swansea, Glamorganshire.
Provis, John, Holyhead, Anglesea.
Rastrick, John U., Birmingham.
Rendel, James M., Plymouth.
Richardson, Joshua, Newcastle-upon-Tyne.
Roentgen, Gerrard Morris, Rotterdam.
Sopwith, Thomas, F.G.S., Newcastle-upon-Tyne.
Smith, James, Deanston, near Stirling, N. B.
Steedman, John, Edinburgh.
Stevenson, Robert, F.G.S., F.R.S. E., Edinburgh.
Stevenson, Alan, M.A., Edinburgh.
Steward, William, Bordeaux.
Stirling, James, Dundee.
Storey, Thomas, St. Helen's-Auckland, Durham.
Stuart, William, Plymouth.
Suermondt, Y. D., Utrecht.
Tennant, Charles, Glasgow.
Thom, Robert, Rothsay, Isle of Bute, N.B.
Thomson, James, Shiffnal, Shropshire.
Thornton, George, Daventry, Northamptonshire.
Thorold, William, Norwich.
Trubshaw, James, Haywood, Staffordshire.
Welsh, Henry, Newcastle-upon-Tyne.
Wilson, Daniel, Paris.
Wilson, Alexander, St. Petersburg.
Wood, Nicholas, Killingworth, near Newcastle.
Woolf, Arthur, Camborne, Cornwall.
Yates, William.

ASSOCIATES.

Abernethy, George, Dover.
Aitchison, George, St. Katharine's, London.
Albano, Benedetto, Piccadilly, Westminster.
Armstrong, John, Bristol.
Ayrton, Lieut. Frederick, Royal Artillery, Bombay.
Baker, George, Montague Place, Russell Square, London.
Baker, Hughbert, Parliament Street, Westminster.
Bartholomew, Charles, Rotherham, Yorkshire.
Barwise, John, St. Martin's Lane, Westminster.
Bevan, John, Buckingham Street, Strand, Westminster.
Billington, William, Pimlico, Middlesex.
Boorer, John, Chelsea, Middlesex.
Borthwick, Michael A., Great George Street, Westminster.
Bourns, Charles, Great Ormond Street, London.
Braidwood, James, Watling Street, London.
Bray, William Bayley, Bow, Middlesex.
Brine, John Augustus, Manchester Buildings, Westminster.
Bull, William, Halifax, Yorkshire.
Carpmael, William, Lincoln's Inn, London.
Combe, James, Nelson Square, Southwark.
Comrie, Alexander, Fludyer Street, Westminster.
Cooper, James, Kentish Town, Middlesex.
Cottam, George, Winsley Street, Oxford Street, London.
Cottam, George Hallen, Oxford Street, London.
Cubitt, Joseph, Great George Street, Westminster.
Cubitt, Lewis, Gray's Inn Road, London.
Cubitt, William, Gray's Inn Road, London.
Davidson, John R., Stone, Staffordshire.
Davison, Robert, Spitalfields, London.
Dent, Edward John, Strand, Westminster.
De Ville, James, Strand, Westminster.

Donkin, Bryan, Jun., New Kent Road, Surrey.
Drewry, Charles, Howland Street, Fitzroy Square, London.
Dundass, John F., Dumfries, N.B.
Errington, John E., Chester.
Freeman, William, Milbank Street, Westminster.
Gordon, Lewis B., Rotherhithe, Surrey.
Green, Joseph, Exeter.
Guest, Josiah John, M.P., F.R.S., F.G.S., F.H.S., Grosvenor Street, London.
Gutch, George, Harrow Road, Middlesex.
Hallen, Benjamin, Winsley Street, Oxford Street, London.
Hawkshaw, John, Vincent Square, Westminster.
Hays, William Bennett, Bermondsey, Surrey.
Heathcoat, John, M.P., London.
Hemming, Samuel, Notting Hill, Middlesex.
Hennett, George, Guildford Street, London.
Heppel, John, Mansion-house Street, London.
Horne, James, F.R.S., City Club House, London.
Houghton, Dugdale, Edgbaston, Birmingham.
Howard, Thomas, Tokenhouse Yard, London.
Howell, James, Vincent Square, Westminster.
Hunter, James, Bow, Middlesex.
Jopling, Joseph, Somerset Street, Portman Square, London.
Jones, Thomas, F.R.S., F.R.A.S., Charing Cross, Westminster.
Kennedy, Henry, Kennington, Surrey.
Kepp, Richard, Chandos Street, Westminster.
Lawrie, Alexander, Manchester.
Leahy, Patrick, Cork.
Leather, John Thomas, Sheffield.
Lynde, James G., Great Queen Street, Westminster.
M'Intosh, David, Bloomsbury Square, London.
May, Charles, City Road, London.
Mitchell, Joseph, Inverness.
Moreland, Richard, Old Street, London.
Moorsom, Captain W. S., St. John's Wood, Middlesex.
Macquiston, Peter, Glasgow.
Moseley, William, King's Road, London.
Nicholls, Nathaniel, Lambeth, Surrey.

OLDHAM, JOHN, St. Martin's Place, Westminster.
PAGE, THOMAS, Rotherhithe, Surrey.
PALMER, WILLIAM, Clerkenwell, Middlesex.
PARSONS, WILLIAM, Leicester.
PATRICK, THOMAS, Fludyer Street, Westminster.
PENN, JOHN, Jun., Greenwich.
POOLE, MOSES, Lincoln's Inn, London.
REID, MAJOR, Royal Engineers, Chatham.
RENTON, A. H., Pimlico, Middlesex.
SEAWARD, SAMUEL, Limehouse, Middlesex.
SIMPSON, WILLIAM, Pimlico, Middlesex.
SPEARMAN, Captain JOHN MORTON, J. U. Service Club, London.
SIMMS, WILLIAM, F.R.A.S., Fleet Street, London.
STEELE, THOMAS, Ennis, Ireland.
SMITH, Captain JOHN THOMAS, Madras Engineers, Madras.
STUTELY, MARTIN J., John Street, Adelphi, London.
STEPHENSON, ROLAND MACDONALD, Upper Thames Street, London.
SYLVESTER, JOHN, Great Russell Street, London.
TAYLOR, THOMAS F., Salisbury Street, Strand, Westminster.
THOMSON, JOHN G., St. Martin's Place, Westminster.
TOMKINS, WILLIAM G., Albion Place, Blackfriars, London.
TOWNSHEND, RICHARD, Highgate, Middlesex.
TREACY, WILLIAM A., St. Martin's Place, Westminster.
TREHERNE, EDMUND, South Molton Street, London.
TUCKER, JOHN SCOTT, Mecklenburg Square, London.
TURNBULL, GEORGE, Cardiff, Glamorganshire.
WATERSTON, JOHN JAMES, Milbank Street, Westminster.
WATKINS, FRANCIS, Charing Cross, Westminster.
WELLS, Major, Royal Engineers, Chatham.
WHITWELL, STEDMAN, Highgate, Middlesex.
WILLIAMS, CHARLES WYE, Liverpool.
WRIGHT, JOHN, Brighton.

HONORARY MEMBERS.

AIKIN, ARTHUR, F.L.S., Society of Arts, Adelphi, Westminster.

BARLOW, PETER, F.R.S., F.R.A.S., Royal Military Academy, Woolwich.

BEAUFORT, Captain FRANCIS, F.R.S., F.R.A.S., F.G.S., Admiralty, London.

BREWSTER, Sir DAVID, LL.D., F.R.S. L. & E., F.R.A.S., Hon. M.R.I.A., Edinburgh.

COLBY, Lieut.-Colonel THOMAS, LL.D., F.R.S. L. & E., M.R.A.S., F.G.S., F.R.A.S., M.R.I.A., Tower, London.

DUPIN, Baron CHARLES, Member of the Institute of France, &c., &c., Paris.

GILBERT, DAVIES, D.C.L., V.P.R.S., F.R.A.S., F.G.S., Hon. M.R.I.A., &c., &c., Eastbourne, Sussex.

GREGORY, OLINTHUS, LL.D., F.R.A.S., Royal Military Academy, Woolwich.

LEGRAND, Mons., Councillor of State, Director General of Roads, Bridges, and Mines in France, &c., &c., Paris.

PARNELL, The Right Hon. Sir HENRY, Bart., M.P., Chester Street, Belgrave Square, London.

PASLEY, Lieut.-Colonel CHARLES WILLIAM, C.B., F.R.S., F.R.A.S., F.G.S. Chatham.

PEARSON, Rev. WILLIAM, D.D., F.R.S., V.P.R.A.S., Islington, Middlesex.

RICKMAN, JOHN, M.A., F.R.S., Duke Street, Westminster.

WALLACE, WILLIAM, M.A., F.R.S.E., F.R.A.S., Edinburgh.

REGULATIONS.

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TO THE

REGULATIONS.

REGULATIONS.

SECTION I.

OF ITS OBJECT.

The Institution of Civil Engineers has been formed for facilitating the acquirement of professional knowledge, and for promoting mechanical philosophy.

SECTION II.

OF ITS CONSTITUTION.

1. The Institution of Civil Engineers shall consist of four classes, *viz.* Members, Corresponding Members, Associates, and Honorary Members.

2. Members shall be persons who are, or have been, engaged in the practice of a Civil Engineer.

3. Corresponding Members shall be persons of the same description, who reside without the limits of the three-penny post.

4. Associates shall be those, whose pursuits constitute branches of Engineering, but who are not Engineers by profession.

5. Honorary Members shall be persons who are not engaged in the practice of a Civil Engineer in this country, but who are men eminent for science, and have written on subjects connected with the profession.

6. The number of Honorary Members shall be limited to forty.

7. The Officers of the Institution shall consist of a President, four Vice-Presidents, and seven Members, who shall constitute a Council for the direction and management of the affairs of the Institution; and of two Auditors, a Treasurer, two Secretaries, and a Collector; all of whom shall be elected annually, and shall be re-eligible.

8. The President, Vice-Presidents, and the seven other Members of the Council, shall be chosen out of the class of Members only; and the Auditors shall be chosen out of the class of Members, or of the class of Associates.

SECTION III.

OF THE ELECTION AND EXPULSION OF MEMBERS, CORRESPONDING MEMBERS, AND ASSOCIATES.

1. All persons desirous of being admitted into the Institution as Members, Corresponding Members, or Associates, must be proposed agreeably to form (A) in the Appendix hereto, wherein must be inserted the Christian name, Surname, and usual place of residence of the candidate, in which the qualifications of the candidate shall also be distinctly specified in such a manner as to enable the Members, Corresponding Members, and Associates, generally to judge of his

eligibility, and which form must, in the case of Members and Associates, be subscribed by at least three Members of the Institution, who shall certify their personal knowledge of such candidate; but in the case of Corresponding Members, it shall be sufficient if one of such three, or more subscribing Members certifies his personal knowledge of the individual proposed. And every person proposed as an Honorary Member must be recommended by at least five Members, who shall certify that he is a person eminent for science, and give the title of one or more works which he may have written on subjects connected with the profession.

2. Every recommendation of a candidate must be delivered to the Secretary, who shall submit the same to the Council for them to inquire and determine whether the candidate is a fit person to be balloted for, and also for which class of Members he should be presented to the Ordinary Meeting.

3. When the Council shall have approved the recommendation of a candidate, the proposition shall be signed by the Chairman of the Council; it shall then be read at the first following Ordinary Meeting, after which, it shall be hung up in their principal meeting room, and there remain until the candidate is balloted for.

4. The ballot shall take place at the second Ordinary Meeting of the Institution after that on which the candidate is proposed.

5. The proportion of votes requisite for the election of any person into either class, shall be at least three-fourths of the ballot.

6. In the election of Members, Corresponding Members, or Associates, a second ballot shall be granted at the same meeting, if immediately demanded by three Members, Corresponding Members, or Associates present.

7. In the event of its being desired to transfer any Member, Corresponding Member, or Associate of the Institution from one class to another class, such proposition, containing the reasons for the desired change, according to form (F), and signed by three Members, Corresponding Members, or Associates, shall be submitted to the Council, as in the case of the admission of Members, Corresponding Members, or Associates, and, if approved by them, shall go through the same forms also, as a candidate for admission into the Society.

8. In case of the non-election of any person balloted for, no notice shall be taken thereof in the minutes.

9. Whenever any person is elected, the Secretary shall immediately inform him of the same by letter (B) in the Appendix, and the election of Honorary Members shall likewise be communicated to them as soon as possible, by a letter suitable to each particular case; and no person shall be considered as an Honorary Member, until he has signified his acquiescence in the election, after which he shall have all the rights and privileges of a Member, except that of filling any office in the Institution.

10. Every person elected a Member, Corresponding Member, or Associate, shall pay his first annual contribution within two months of the day of his election, otherwise his election shall be void. But in the case of Corresponding Members not resident in Great Britain, the Council shall have power to extend this period as they may judge proper.

11. Every Member, Corresponding Member, and Associate elected, shall be required to sign the form (C) in the Appendix, and having likewise paid his first annual contribution, shall be admitted at the first ordinary meeting of the Institution at which he is present, according to the ensuing form: *viz.* the President or Chairman of the Meeting, addressing him by name, shall say, "As President,

or as Chairman of this Meeting of the Institution of Civil Engineers, I introduce Mr. *B. W.* as a [*as may be*] thereof."

12. If at any time there shall appear cause for the expulsion of any Member, Corresponding Member, or Associate, such proposition shall be handed to the Council, who, if they think fit, shall call a special General Meeting for the purpose, but no Member, Corresponding Member, or Associate, can be expelled without a report from the Council; and if one-half of the Members then present, at such special General Meeting, agree that such Member, Corresponding Member, or Associate be expelled, the President, or other Officer or Member in the Chair, shall declare the same accordingly, and the Secretary shall forthwith communicate the same to such Member, Corresponding Member, or Associate, according to the form (D) in the Appendix.

SECTION IV.

OF THE ELECTION OF THE OFFICERS.

1. The President, Vice-Presidents, Council, two Auditors, Treasurer, two Secretaries, and Collector, shall be elected annually by ballot, at the General Meeting, on the third Tuesday in January.

2. That all persons to be eligible as Officers of this Institution, must be put in nomination at the Ordinary Meeting, immediately preceding the Annual General Meeting.

SECTION V.

OF THE CONTRIBUTION OF MEMBERS, CORRESPONDING MEMBERS, AND ASSOCIATES.

1. The Contribution of each Member shall be three guineas per annum; the first of which shall be payable at the time of his election, and every payment shall become due in advance, on the first day of January then next following.

2. The Contribution of each Corresponding Member shall be two guineas per annum; the first of which shall be payable at the time of his election, and every payment shall become due in advance, on the first day of January then next following.

3. The Contribution of each Associate shall be two guineas and a half per annum; the first of which shall be due at the time of his election, and every subsequent payment shall, in like manner, become payable in advance, on the first day of January then next following. Any Member, Corresponding Member, or Associate, residing in the United Kingdom, may, however, compound for his annual contributions by the payment of twenty guineas, and any Member, Corresponding Member, or Associate, residing abroad, may compound for his annual contribution by the payment of ten guineas.

4. New Members, Corresponding Members, or Associates, shall pay the sum of one guinea, as an admission fee.

5. Every Member, Corresponding Member, and Associate, is expected to produce to the Institution, at least one unpublished communication in each

session, or present a book, map, plan, model, or instrument not already in possession of the Institution; or any drawing, model, or description of a work already executed, will be acceptable.

6. Every Member, Corresponding Member, and Associate, shall be considered as belonging to the Institution, and as such, liable to the payment of his annual contribution, until he has either forfeited his claim, or has signified to the Secretary in writing his desire to resign, when his name shall be erased from the list of Members.

7. Whenever any Member, Corresponding Member, or Associate, shall be two years in arrear in the payment of his annual contribution, the Council shall direct the Secretary to send to such Member, Corresponding Member, or Associate, a letter of the form (E) in the Appendix. And if the arrears shall not be paid within six months after the forwarding of such letter, the name of the Member, Corresponding Member, or Associate so offending shall be publicly suspended, in the meeting rooms of the Institution, as a defaulter, together with the amount of contribution due by him; and such Member, Corresponding Member, or Associate, shall not enjoy any of the privileges and advantages thereof until his arrears be paid.

SECTION VI.

OF THE PRESIDENT.

The President shall be a person eminent as a Civil Engineer, and shall take the Chair at all meetings of the Institution at which he is present, and shall regulate and keep order in the proceedings. It shall likewise be his duty to state and put questions, according to the sense and intention of the meeting, and to carry into effect the Regulations of the Institution.

SECTION VII.

OF THE VICE-PRESIDENTS.

In the absence of the President, it shall be the duty of the Vice-Presidents to preside in rotation at the meetings of the Institution, and to state and put questions, keep order, and regulate the proceedings. But in case of the absence of the President and all the Vice-Presidents, the Members present may elect any one of their number to take the Chair at that meeting.

SECTION VIII.

OF THE COUNCIL.

1. The direction and management of all the affairs of the Institution shall be confided to the Council.

2. The Council shall meet at the house of the Institution, at least once every fortnight during the session; but any two Members thereof may, by letter to the Secretary, require an extra meeting to be called, three days' notice of which must be given to each of the Members of the Council.

3. At any Meeting of the Council, three Members thereof shall constitute a quorum.

4. All questions shall be decided in the Council by vote; but at the desire of any two Members present, the determination of any subject shall be postponed to the succeeding Meeting.

5. An annual Account of the general state of the funds of the Institution

and of the Receipts and Expenses of the past year, shall be made out by the Council, which after being examined by the Auditors, shall be laid before the Annual General Meeting.

6. The Council shall draw up a Yearly Report on the state of the Institution, in which shall be given an abstract of all the proceedings, and such Report shall be read at the Annual General Meeting.

SECTION IX.

OF THE AUDITORS.

The two Auditors shall audit the accounts of the Institution annually, previous to the General Meeting.

SECTION X.

OF THE TREASURER.

1. The Treasurer shall be a Banker in London, with whom all money belonging to the Institution shall be deposited by the Council, on account and for the use of the Institution.

2. No sum of money, payable on account of the Institution, amounting to five pounds and upwards, shall be paid, except by order of the Council, signed by three Members of the Council and the Secretary.

3. All admission fees, and life subscriptions, together with one moiety of the surplus money, shall be annually invested as an increasing fund for the use and advantage of the Institution.

SECTION XI.

OF THE SECRETARIES.

The duty of the Secretaries shall be to attend the meetings of the Institution and of the Council—to take minutes of all their proceedings, and enter them in the proper books—to read the minutes of the preceding meeting—to announce any donations made to the Institution—to give notice of any candidate proposed for admission, or to be balloted for—and to read the letters and papers presented to the Institution in the order of time in which they were received, unless the Council shall otherwise determine: also to keep the accounts of the Institution.

SECTION XII.

OF THE COLLECTOR.

The duty of the Collector shall be to collect all monies due to the Institution, and pay the amounts to the Treasurer, and to lay accounts of the sums so received and paid to the Treasurer, before the Council.

SECTION XIII.

OF THE ORDINARY MEETINGS.

1. The sessions of the Institution shall commence annually on the second Tuesday in January, and ordinary meetings shall be held on every succeeding Tuesday, until May, inclusive, but it shall be in the power of the Council to protract the sessions if it should seem necessary. The Chair may be taken when five Members, Corresponding Members, or Associates, are present.

2. The business of the Institution shall commence at eight o'clock in the

evening precisely, and be conducted according to the order prescribed in the Bye-Laws.

3. Every Member, Corresponding Member, and Associate, shall have the privilege of introducing a visitor to be present at the public business of the Institution, on writing his name in a book provided for that purpose.

4. At the Ordinary Meetings of the Institution, nothing relating to its regulation or management shall be brought forward, and no motion shall be made after ten o'clock.

SECTION XIV.

OF THE ANNUAL GENERAL MEETING.

A General Meeting of the Institution shall be held annually, on the third Tuesday in January, at seven o'clock in the evening, to receive and deliberate upon the report of the Council on the state of the Institution, and to elect the officers for the ensuing year.

SECTION XV.

OF SPECIAL GENERAL MEETINGS.

1. The Council may, at any time, call a Special General Meeting of the Institution for a specific purpose; and they are at all times bound to do so on the written requisition of ten Members, Corresponding Members, or Associates, which shall specify the nature of the business to be transacted.

2. No alteration of the rules or regulations shall be made, except at a Special General Meeting of the class of Members only.

3. Members or Associates resident in London shall have three days' notice of the time of such meeting, and shall be, at the same time, informed of the nature of the business to be brought forward: and no other question shall be discussed at such meeting.

SECTION XVI.

OF COMMITTEES AND LECTURES.

1. The Council shall have power to appoint Committees, for the purpose of investigating specific subjects connected with the objects of the Institution; and the reports of such Committees shall be submitted to the Council, previously to their being read to the Institution.

2. The Council shall have power to grant, from time to time, as they may think fit, the use of the rooms of the Institution to any number of Members who may be desirous of having Lectures delivered to them on subjects connected with the profession, provided always that the extra expenses thereof be defrayed by those who attend such Lectures.

SECTION XVII.

OF ALTERING THE REGULATIONS.

1. The Council shall, when they consider it expedient to propose the enactment of any new regulation, or the alteration or repeal of any existing one, summon a Special General Meeting of Members to decide on the same, and the Council may also call a Special General Meeting of Members at any time during the session for such purpose.

2. The alteration or repeal of any existing regulation may be recommended

to the Council, such recommendation to be written out and signed by any ten Members, Corresponding Members, or Associates of the Institution; and on the recommendation thus made the Council shall decide.—If such decision be not satisfactory to the Members, Corresponding Members, or Associates proposing the alteration, the Council shall, if required, submit the same to a Special General Meeting of Members to be convened for that purpose.

3. No new regulation, nor alteration or repeal of any existing regulation, shall be proposed at any meeting of the Institution, except in the manner here described.

SECTION XVIII.

OF THE PROPERTY OF THE INSTITUTION.

1. The whole of the property and effects of the Institution, of what kind soever, shall be vested in the Council of the Institution for the time being, to be held in trust for its use.

2. Every paper, map, plan, or drawing, which may be presented to the Institution, shall be considered as the property thereof, unless there shall have been any previous arrangement to the contrary; and the Council may publish the same in any way, and at any time, they may think proper. But should the Council refuse or neglect to publish such paper or other communication within a reasonable time, the author thereof shall have a right to copy the same, and publish it as he may think fit.—No other person shall publish any communication belonging to the Institution, without the previous consent of the Council.

3. No books, papers, plans, maps, or other property belonging to the Institution, shall be taken out of the house thereof; but every Member, Corre-

sponding Member, or Associate shall have a right at all seasonable hours to inspect the same, and to make extracts and copies therefrom at his own expense.

SECTION XIX.

OF DONATIONS AND BEQUESTS.

1. The names of all persons who shall contribute to the Library, to the Collection, or to the general Fund of the Institution, shall be read at the Annual General Meeting, and such persons shall be recorded as benefactors in the next volume of the Transactions thereafter to be published.

2. Every person desirous of bequeathing to the Institution any manuscripts, books, maps, plans, drawings, instruments, or other personal property, is requested to make use of the following form in his will; viz.—

> "I give and bequeath to the INSTITUTION OF CIVIL ENGINEERS, incorporated June 3, 1828, [*here enumerate and particularize the effects or property intended to be bequeathed,*] and I hereby declare that the receipt of the Treasurer of the said Institution for the time being shall be an effectual discharge to my executors for the said legacy."

BYE-LAWS.

I. At the Meeting of the Institution every Tuesday evening, the following order of business shall be attended to, as closely as circumstances will admit:—

1. The Minutes of the previous meeting to be read and confirmed, and signed by the Chairman; and no entry shall be considered valid until thus completed.
2. The Minutes of the conversation on questions discussed at the previous meeting to be read and corrected.
3. New Members, Corresponding Members, or Associates, to be introduced to the meeting.
4. Candidates for admission to be balloted for.
5. Business arising out of the Minutes to be entered on.
6. Communications received since the last meeting to be announced, and read, if required.
7. Presents to be acknowledged.
8. Communications from the Council to be brought forward.
9. Questions on the printed circular to be discussed.

II. After a discussion on questions at an Ordinary Meeting, the Chairman is expected to sum up the opinions that have been given, and declare what appears

to be the sense of the meeting on the subjects discussed, together with his own opinion.

III. A weekly Circular Letter shall be sent to all the Members requiring it, announcing the evening and time of meeting, and containing a list of Questions for discussion, to be varied at the discretion of the Council, with the name of the proposer of the question, and the class of members to which he belongs.

IV. All questions for discussion must be proposed by Members, Corresponding Members, or Associates of the Institution; be first delivered to the Secretary, and by him submitted to the Council, who shall decide upon the adoption of those that are suitable and in accordance with the objects of the Institution.

V. A Circular Letter shall be sent to all the country members at the commencement of each session, with a list of questions that are appointed for discussion at the ordinary meetings of the Institution, requesting communications from the Members, Corresponding Members, and Associates on them.

A similar Letter shall also be transmitted about the middle of the session, with the addition of any new questions that may have been brought forward and accepted: and at the end of the session, a list of questions shall also be sent to all the Members, Corresponding Members, and Associates, in order to collect information during the recess. Each Letter shall contain a list of the written communications that have been made to the Institution.

VI. Each Member, Corresponding Member, and Associate, is expected to insert his name in a book kept for this purpose, whenever he attends at the room of the Institution, whether at a regular meeting of the Society, or at any other times, and also the name and residence of any visitor he may introduce.

VII. The Minutes of conversation that are taken by the Secretary, shall be carefully pasted in a book in the order in which they occur, that Members, Corresponding Members, and Associates may have easy access to them, and that they may also be preserved as the original records of the Transactions.

VIII. It is expected that any gentleman addressing the meeting shall stand for this purpose, in order to prevent interruption, and to command the attention of the meeting; and the person first rising shall have the precedence in speaking, upon which, if there is any doubt, the Chairman shall decide.

IX. No persons, but Members, Corresponding Members, Associates, and Honorary Members, can be allowed, on any pretence, to peruse any of the books, papers, or records belonging to the Institution, except by permission of the Council, to whom a letter must be addressed through the Secretary, stating the precise object of the application.

X. That the names of Candidates proposed, and of those by whom they are proposed, and the names of new Members, Corresponding Members, and Associates, be inserted in the weekly Circular Letters, with the date of the admission of such Members, Corresponding Members, and Associates, as soon as they have complied with the rule by which their election is confirmed.

XI. No person can be eligible to be chosen as a Member who is under the age of twenty-one years; and no person can be eligible to fill any office in the Institution, who is under the age of twenty-five years.

XII. That any Member, Corresponding Member, Associate, or Honorary Member, who may have occasion to designate his connexion with the Institution, in print or otherwise, shall state the Class to which he belongs.

APPENDIX

TO THE REGULATIONS.

FORM, A.

A. B. [*here state the Christian name, Surname, and usual place of residence, with the qualifications of the Candidate.*]

being desirous of admission into the Institution of Civil Engineers, we, the undersigned, from our personal knowledge, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of 18 .

FORM, B.

Sir,

I beg to inform you, that on ———— you were elected a [*as may be*] of the Institution of Civil Engineers. But in conformity with the Regulations thereof, your election cannot be confirmed until the enclosed form be returned with your signature, and until your first annual contribution be paid, the amount being ————, and which unless paid within two months the election is void.

You will therefore be good enough to cause the same to be done.

I am, Sir,

Your obedient humble Servant,

———— Secretary.

*** The annual subscriptions become due on the first of January, and are to be paid in advance.

FORM, C.

I, the undersigned, being elected a [ ] of the Institution of Civil Engineers, do hereby promise that I will be governed by the Regulations of the said Institution, as they are now formed, or as they may hereafter be altered, amended, or enlarged. And that I will advance the objects of the said Institution as far as shall be in my power, and will attend the usual meetings thereof as often as I conveniently can. Provided that whenever I shall signify in writing to the Secretary for the time being, that I am desirous of withdrawing my name therefrom, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of 18 .

FORM, D.

Sir,

It is my duty to acquaint you, that by a determination of the Institution of Civil Engineers, pursuant to their Regulation Number 12, Section III., you are no longer a of that Body.

I am, Sir,

Your obedient humble Servant,

——— Secretary.

FORM, E.

Sir,

The Council of the Institution of Civil Engineers have directed me to inform you,

that your contribution thereto has been in arrear since ————————, the amount being ————————.

I have therefore to request that you will order the payment thereof.

I am, Sir,

Your obedient humble Servant,

———————— Secretary.

FORM, F.

We whose names are hereunto subscribed submit to the Council of the Institution of Civil Engineers, the propriety of transferring *A. B.* from the Class of in which he was elected, to the class of Members, because, &c., &c.

Witness our hands, this day of 18 .

CHARTER

OF

INCORPORATION.

JUNE 3, 1828.

Charter.

George the Fourth, by the Grace of God, of the United Kingdom of Great Britain and Ireland King, Defender of the Faith: To all to whom these presents shall come, Greeting:

Whereas *Thomas Telford*, of Abingdon Street, in our city of Westminster, Esquire, a Fellow of the Royal Societies of London and Edinburgh, and others of our loving subjects, have formed themselves into a Society for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer, being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in states both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange, and in the construction of ports, harbours, moles, breakwaters and lighthouses, and in the art of navigation by artificial power for the purposes of commerce, and in the construction and adaptation of machinery, and in the drainage of cities and towns: And have subscribed and collected considerable sums of money for those purposes: And We have been besought to grant to them, and to those who shall hereafter become members of the same Society, our Royal Charter of Incorporation, for the purposes aforesaid:

Now KNOW YE, that We, being desirous of encouraging a design so laudable and salutary, of our especial grace, certain knowledge, and mere motion, have willed, granted, and declared: And do by these presents, for us, our heirs and successors, will, grant, and declare, that the said *Thomas Telford*, and such others of our loving subjects as have formed themselves into and are now members of the said Society, or who shall at any time hereafter become members thereof, according to such regulations or bye-laws as shall be hereafter framed or enacted, shall, by virtue of these presents, be the members of, and form one Body Politic and Corporate, for the purposes aforesaid, by the name of "THE INSTITUTION OF CIVIL ENGINEERS;" by which name they shall have perpetual succession, and a common seal, with full power and authority to alter, vary, break, and renew the same, at their discretion; and by the same name to sue, and be sued, implead, and be impleaded, answer, and be answered unto, in every court of us, our heirs and successors; and be for ever able and capable in the law, to purchase, receive, possess, and enjoy to them and their successors, any goods and chattels whatsoever, and also be able and capable in the law (notwithstanding the statutes of mortmain) to take, purchase, possess, hold and enjoy to them and their successors, a Hall, and any messuages, lands, tenements, or hereditaments whatsoever, the yearly value of which, including the site of the said Hall, shall not exceed in the whole the sum of one thousand pounds, computing the same respectively at the rack-rent which might have been had or gotten for the same respectively at the time of the purchase or acquisition thereof; and to act in all the concerns of the said body politic and corporate for the purposes aforesaid, as fully and effectually to all

intents, effects, constructions, and purposes whatsoever, as any other of our liege subjects, or any other body politic or corporate in our United Kingdom of Great Britain and Ireland, not being under any disability, might do in their respective concerns. And We do hereby grant our especial licence and authority unto all and every person and persons, bodies politic and corporate, (otherwise competent,) to grant, sell, alien, and convey in mortmain, unto and to the use of the said Society, and their successors, any messuages, lands, tenements, or hereditaments, not exceeding such annual value as aforesaid. And our will and pleasure is, and We further grant and declare, that there shall be a General Meeting of the members of the said body politic and corporate, to be held from time to time, as hereinafter mentioned, and that there shall always be a Council, to direct and manage the concerns of the said body politic and corporate; and that the general meetings and the council shall have the entire direction and management of the same, in the manner, and subject to the regulations, hereinafter mentioned. But our will and pleasure is, that at all general meetings, and meetings of the council, the majority of the members present, and having a right to vote thereat respectively, shall decide upon the matters propounded at such meetings, the person presiding therein having, in case of an equality of numbers, a second or casting vote. And We do hereby also will, grant, and declare, that the council shall consist of a President, four Vice-Presidents, and not more than fifteen, nor less than seven other members, to be elected out of the members of the said body politic and corporate; and that the first members of the council, exclusive of the President, shall be elected within six calendar months after the date of this our Charter; and that the said *Thomas*

Telford shall be the first President of the said body politic and corporate. And We do hereby further will, grant, and declare, that it shall be lawful for the members of the said body politic and corporate, hereby established, to hold general meetings once in the year, or oftener, for the purposes hereinafter mentioned, (viz.); That the general meeting shall choose the President, Vice-Presidents, and other members of the council; that the general meetings shall make and establish such bye-laws as they shall deem to be useful and necessary for the regulation of the said body politic and corporate, for the admission of members, for the management of the estates, goods and business of the said body politic and corporate, and for fixing and determining the manner of electing the President, Vice-Presidents, and other members of the council, and the period of their continuance in office; as also of electing and appointing a Treasurer, two Auditors, and two Secretaries, and such other officers, attendants, and servants, as shall be deemed necessary or useful for the said body politic and corporate; and such bye-laws from time to time shall or may alter, vary, or revoke, and shall or may make such new and other bye-laws as they shall think most useful and expedient, so that the same be not repugnant to these presents, or to the laws and statutes of this our Realm; and shall and may also enter into any resolution, and make any regulation, respecting any of the affairs and concerns of the said body politic and corporate, that shall be thought necessary and proper. And We further will, grant, and declare, that the council shall have the sole management of the income and funds of the said body politic and corporate, and also the entire management and superintendence of all the other

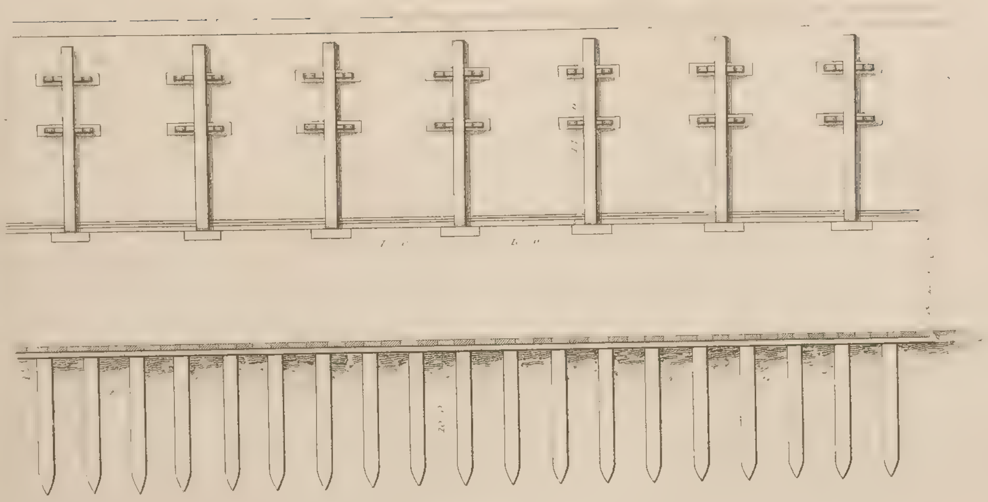
affairs and concerns thereof; and shall or may, but not inconsistently with, or contrary to the provisions of this our Charter, or any existing bye-law, or the laws and statutes of this our Realm, do all such acts and deeds as shall appear to them necessary or essential to be done, for the purpose of carrying into effect the objects and views of the said body politic and corporate. And We further will, grant, and declare, that the whole property of the said body politic and corporate shall be vested, and we do hereby vest the same solely and absolutely in the members thereof, and that they shall have full power and authority to sell, alienate, charge or otherwise dispose of the same, as they shall think proper; but that no sale, mortgage, incumbrance, or other disposition of any messuages, lands, tenements, or hereditaments, belonging to the said body politic and corporate, shall be made, except with the approbation and concurrence of a general meeting. And We lastly declare it to be our Royal will and pleasure, that no resolution, or bye-law, shall on any account or pretence whatsoever be made by the said body politic and corporate in opposition to the general scope, true intent, and meaning of this our Charter, or the laws or statutes of our Realm; and that if any such rule or bye-law shall be made, the same shall be absolutely null and void, to all intents, effects, constructions, and purposes whatsoever. In witness whereof We have caused these our Letters to be made Patent. Witness Ourself at our Palace of Westminster, this third day of June, in the ninth year of our reign.

By Writ of Privy Seal. SCOTT.

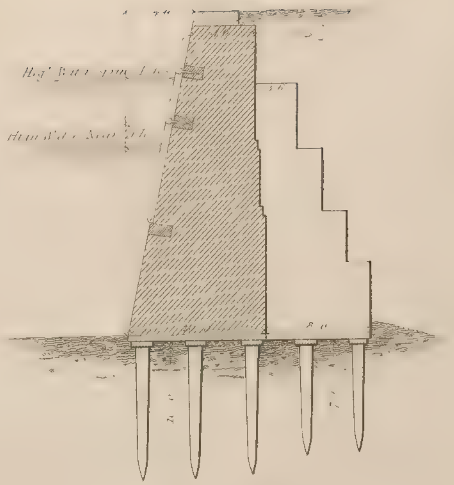

Charriot Str.
George Street
Dock
Timber Quay
Savile Street
OLD
Water Works St.
Car Lane
Legal Quay
Whitefriars Gate
Waterhouse Lane
Quay
JUNCTION DOCK
Quay
Eastern Gate
Dagger Lane
Church
Castle Street
Myton Gate
Market Place
HUMBER DOCK
Quay
Blanket Row
Blackfriars Gate
Queen Street
Theatre
New Road
Wellington St.
Ship Yard
BASIN
Nelson Str.
T H


Sutton Drain
RIVER HULL
North Bridge
Yards
Dry Dock
Basin
DOCK
Bonding Yard
Dock House
Salthouse Lane
George
Chapel Lane
Bishops Lane
Scale Lane
Pond
High St.
THE OLD HARBOUR
Garrison Road
THE GARRISON
E H U M B E R
Note. The dotted line thus __ shews the direction of the ancient fortifications and line thus __ the boundary of the Companys property.

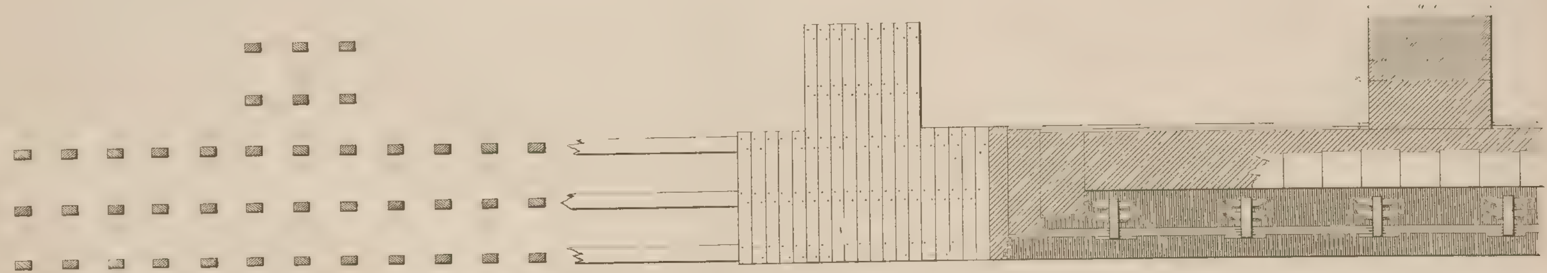
HULL DOCKS, OLD DOCK WALL.



ELEVATION

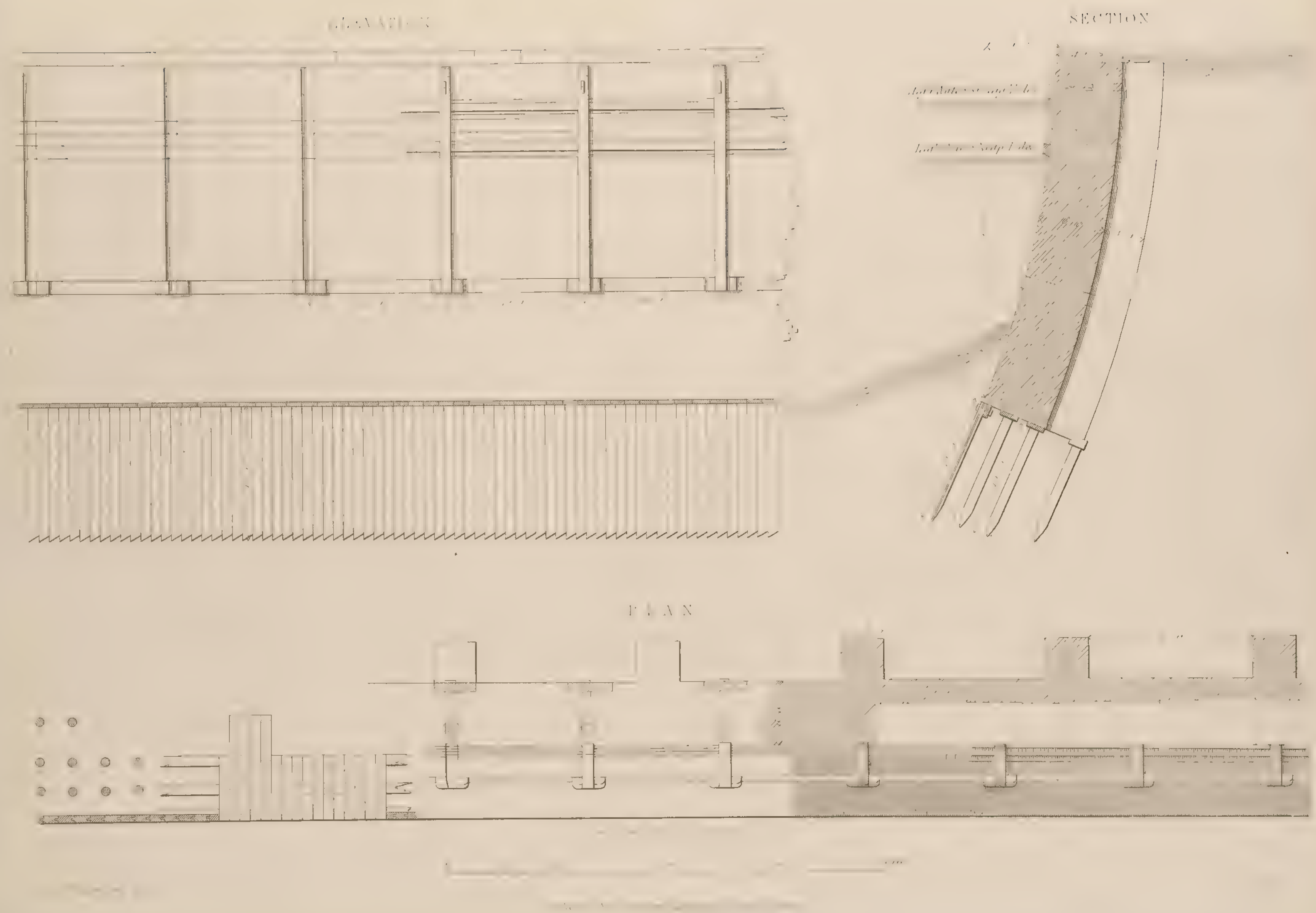


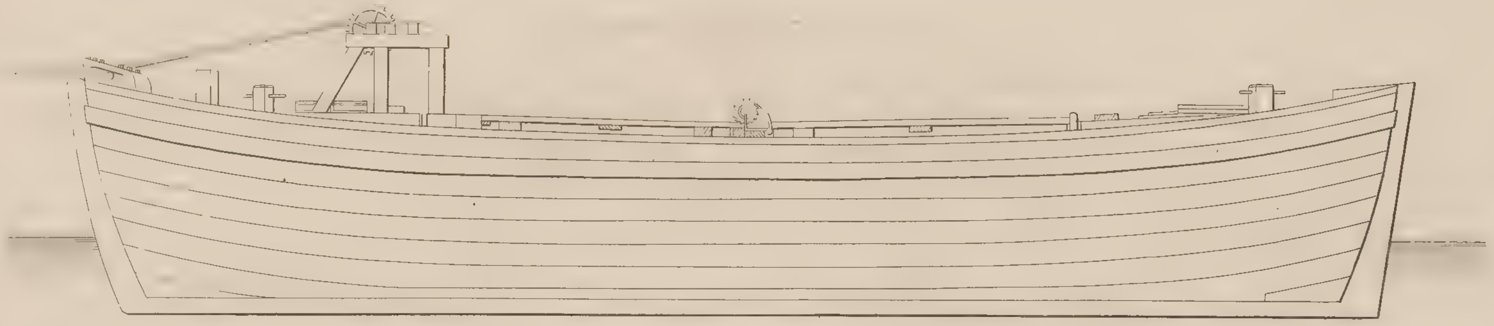
CROSS SECTION



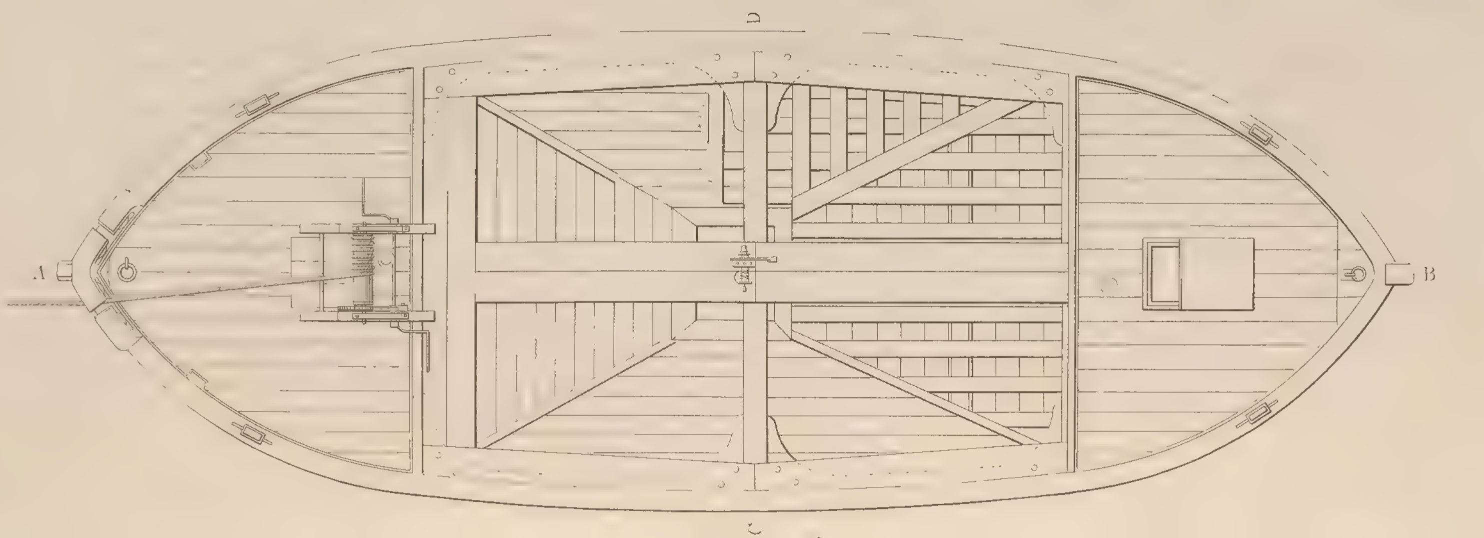
PLAN

HULL DOCKS. HUMBER LOCK WALL.

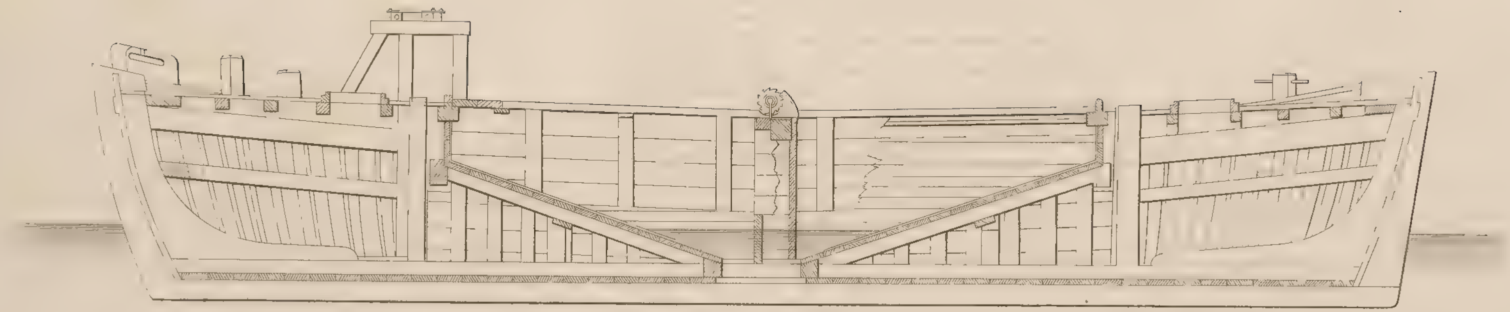




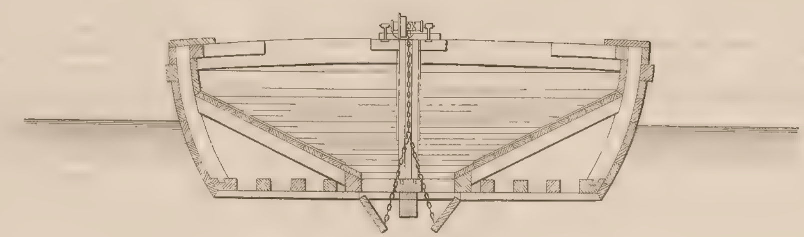
ELEVATION.



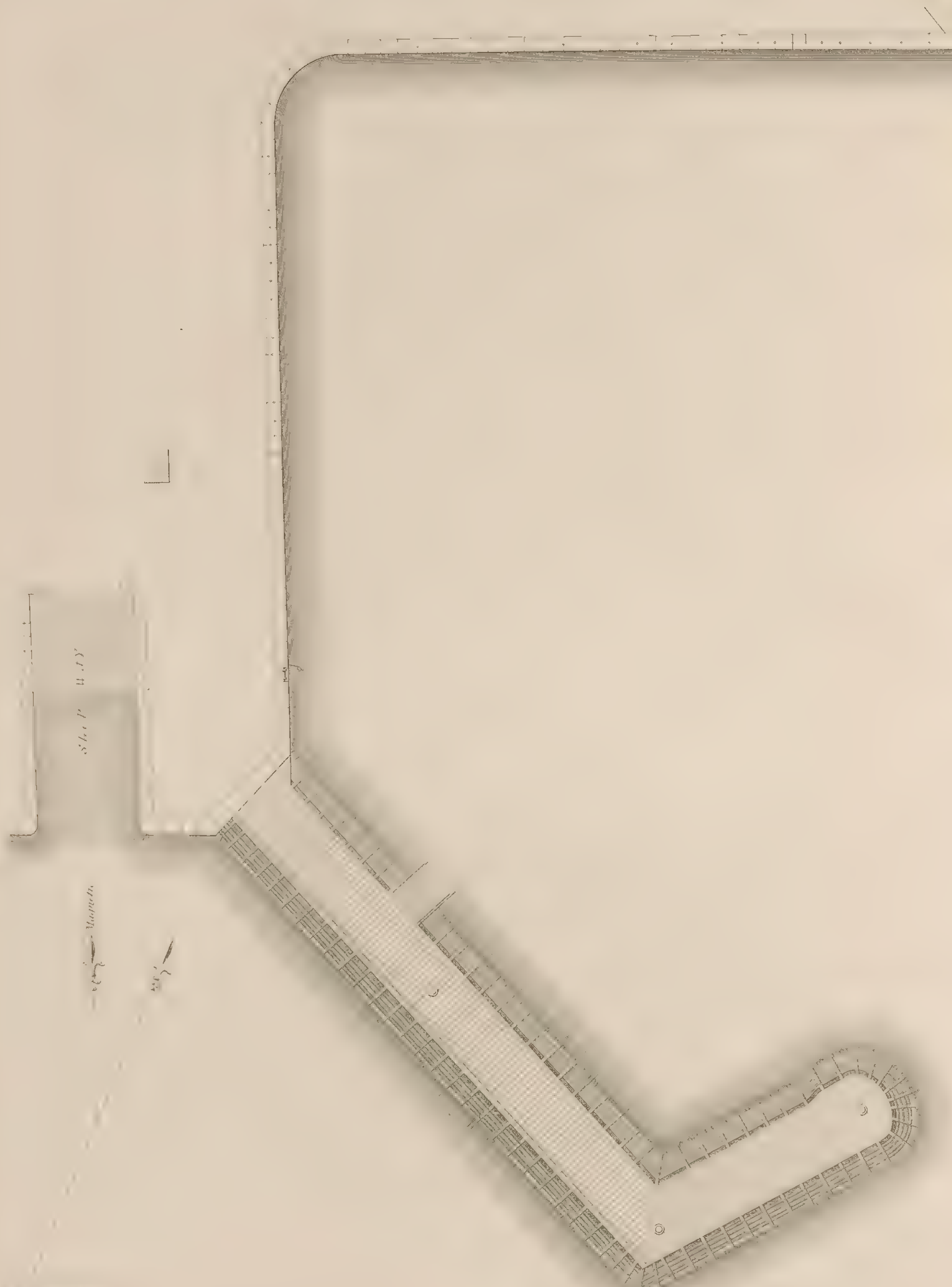
PLAN



SECTION A B.



SECTION C D



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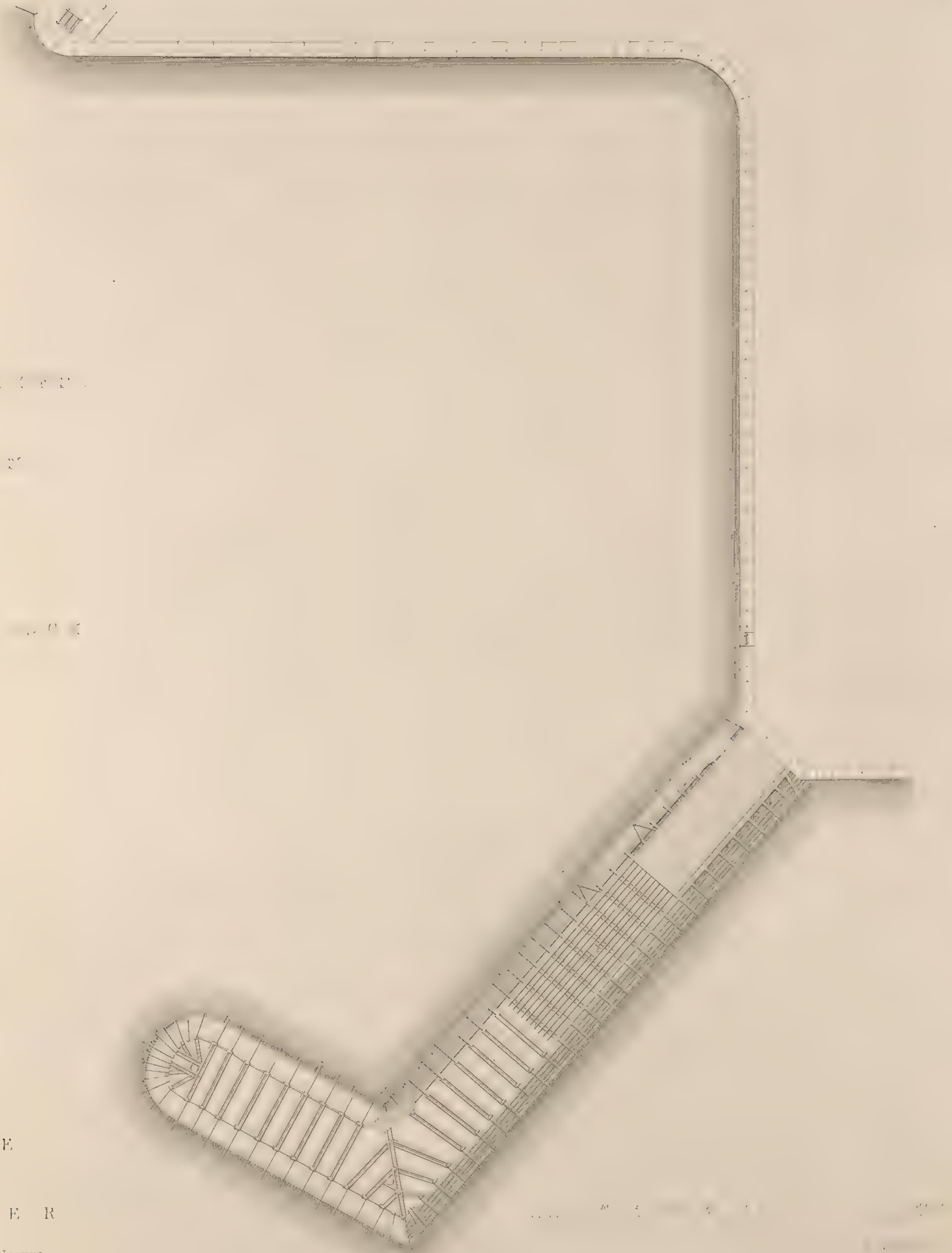
John Weale, Architect



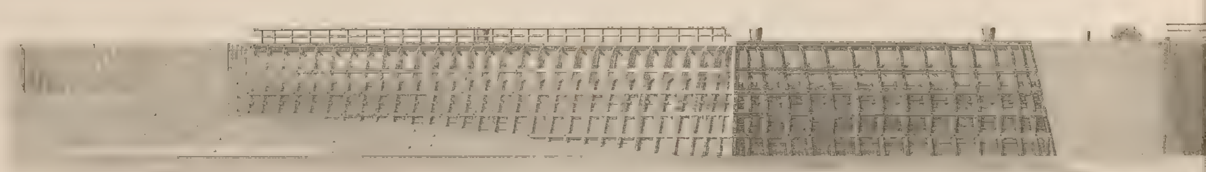
O F

H E

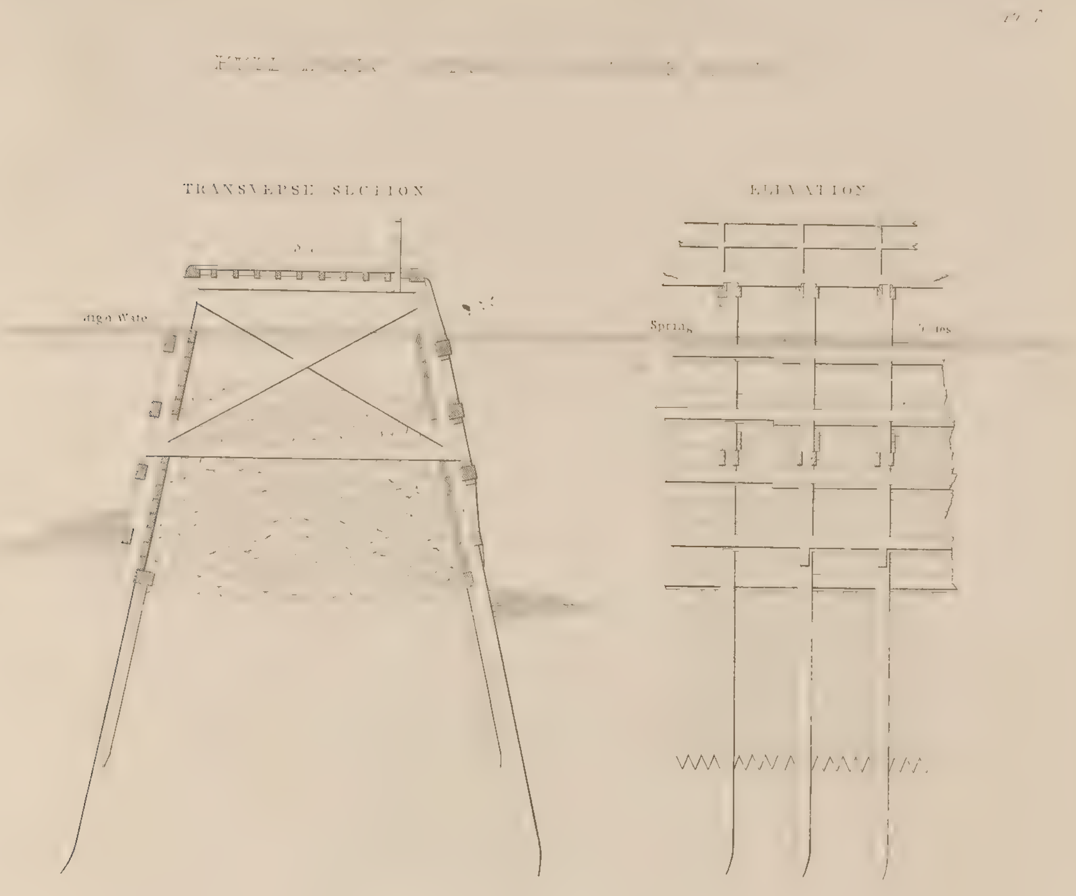
M B E R

by G. A. Jermyn.

ural Library, 59. High Holborn

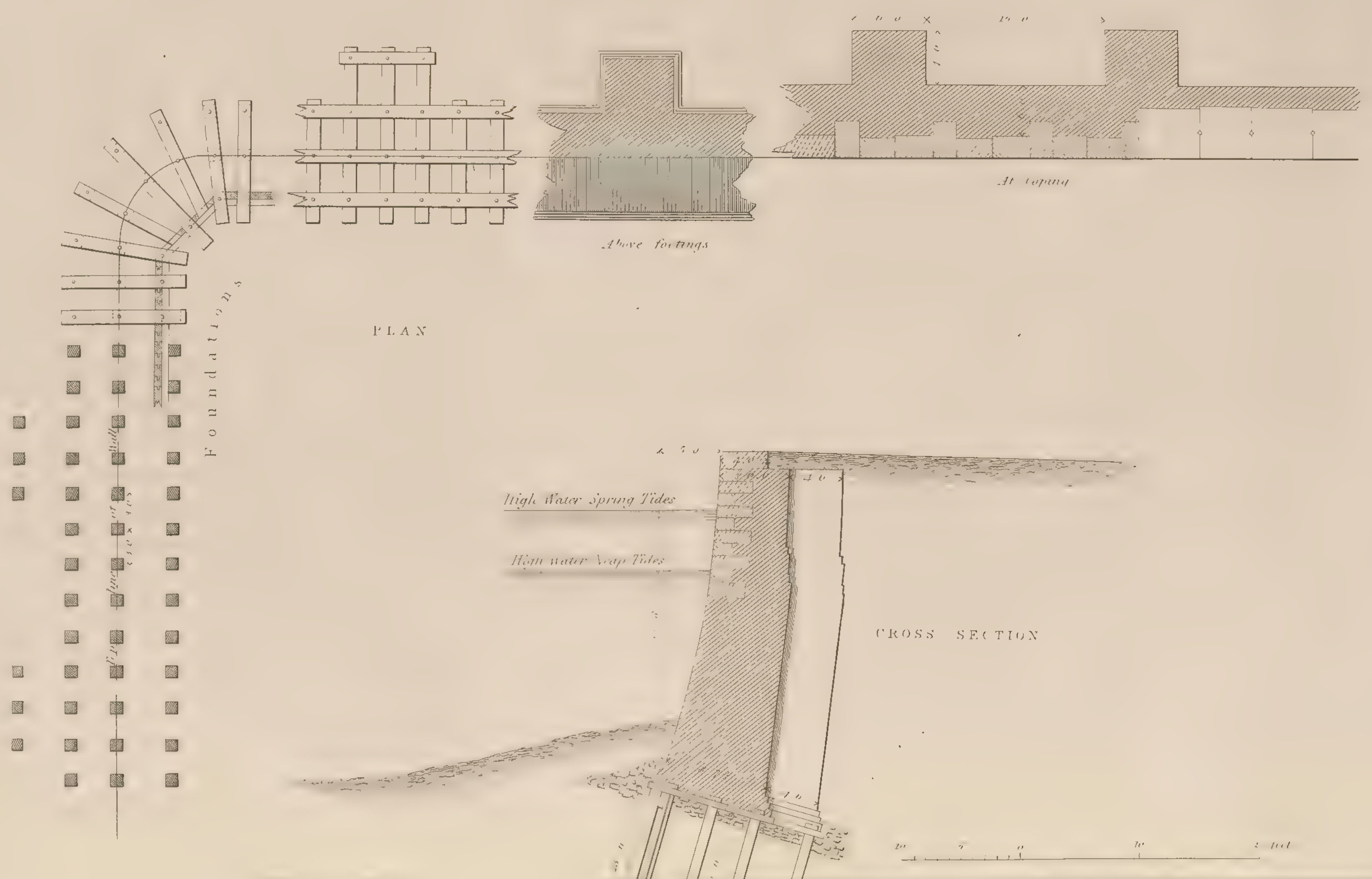


duced by G.A.Jermyn

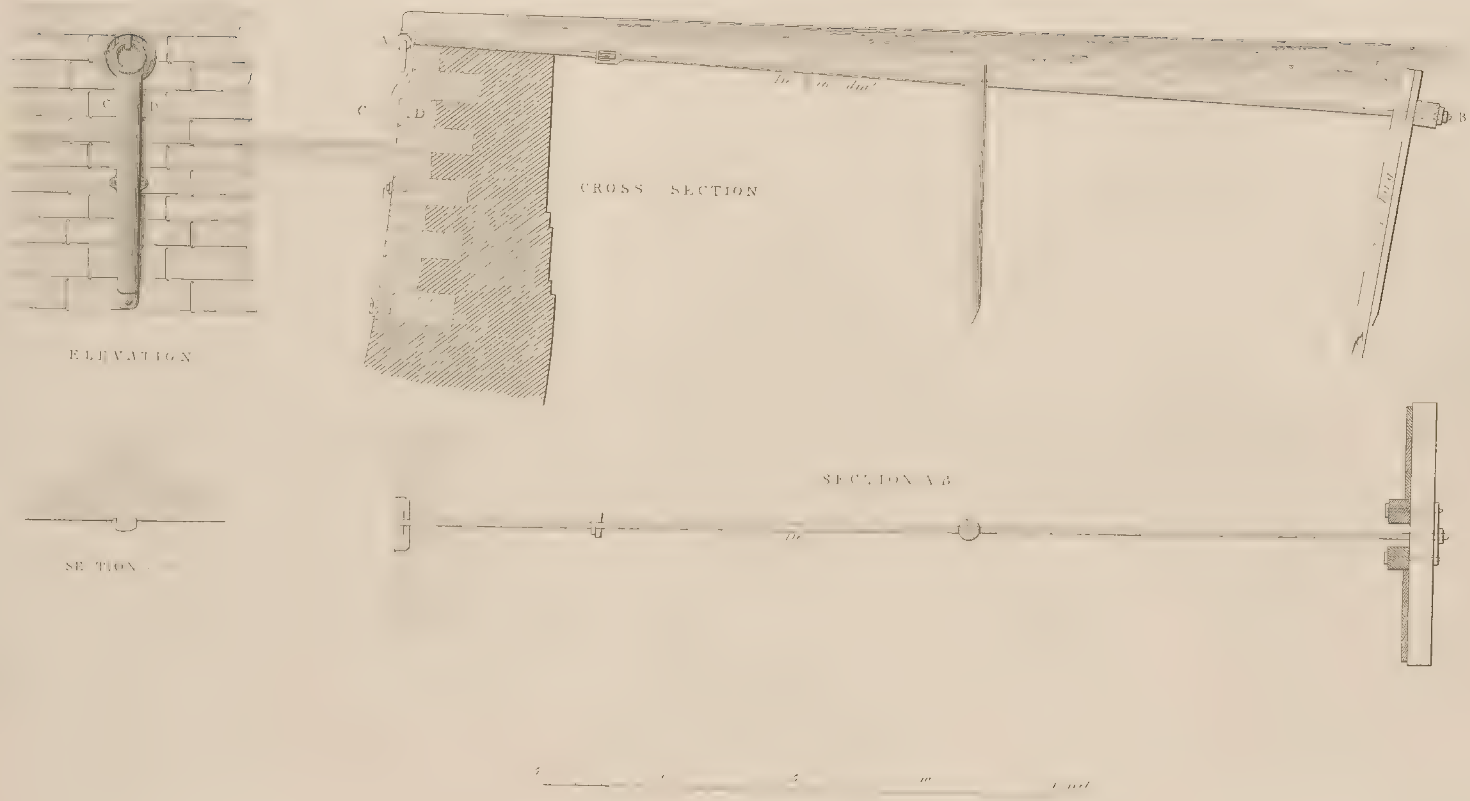

TRANSVERSE SECTION
ELEVATION
Spring
PLAN

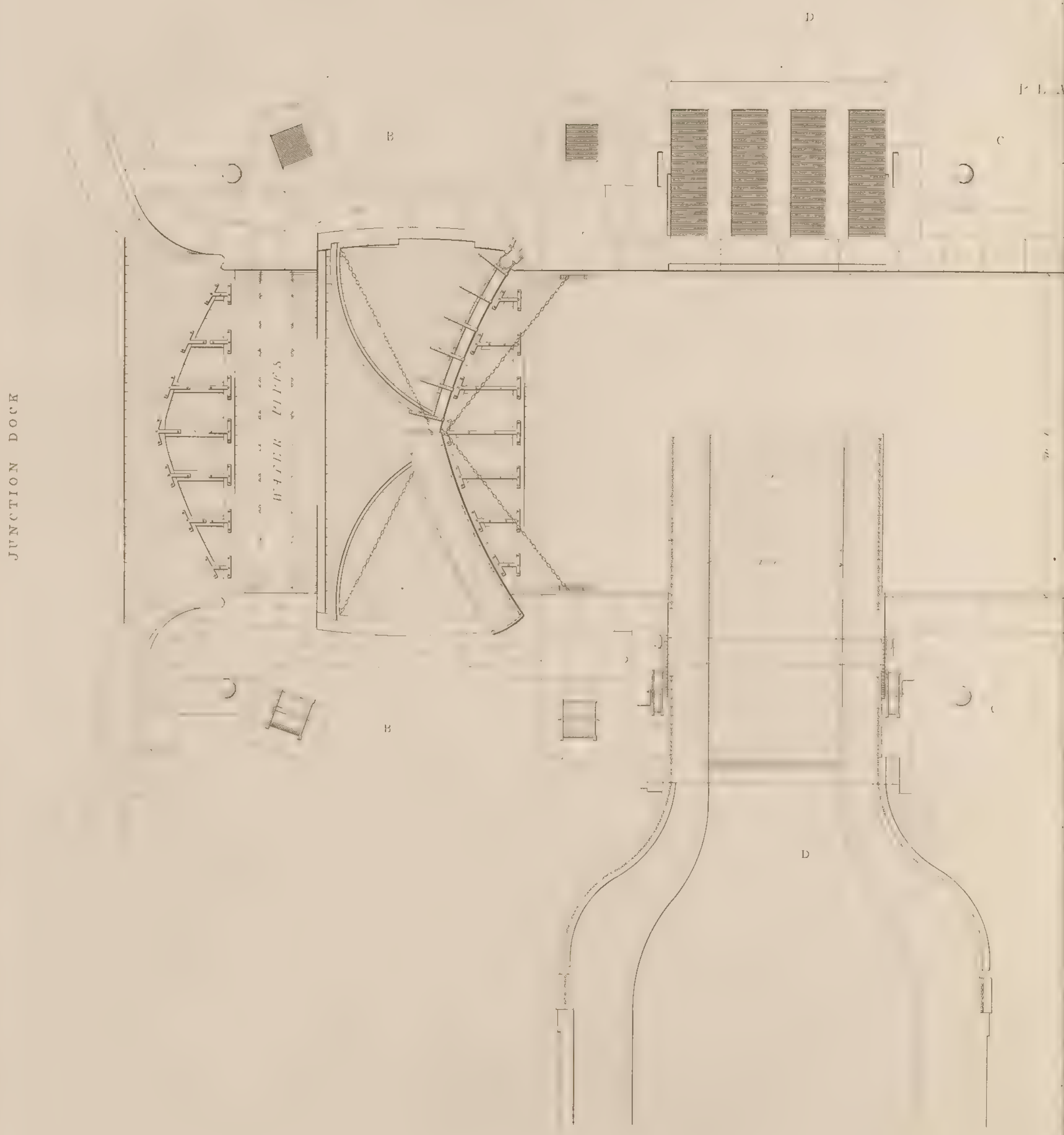
Pl. 8

ROYAL DOCKS — JUNCTION DOCK WALL



RING MOORINGS ON THE EAST SIDE OF DOCK





J & D Timperley del

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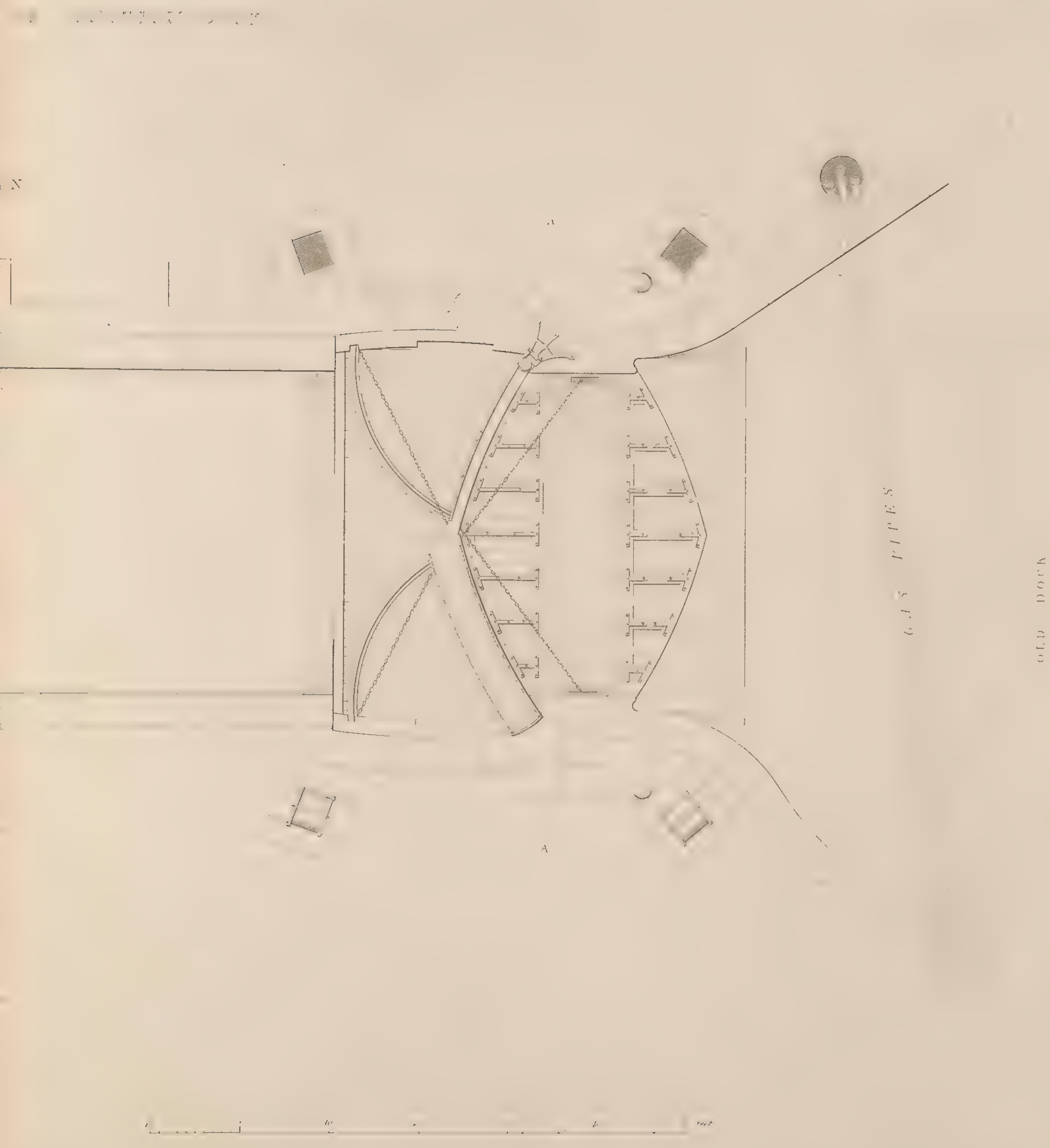
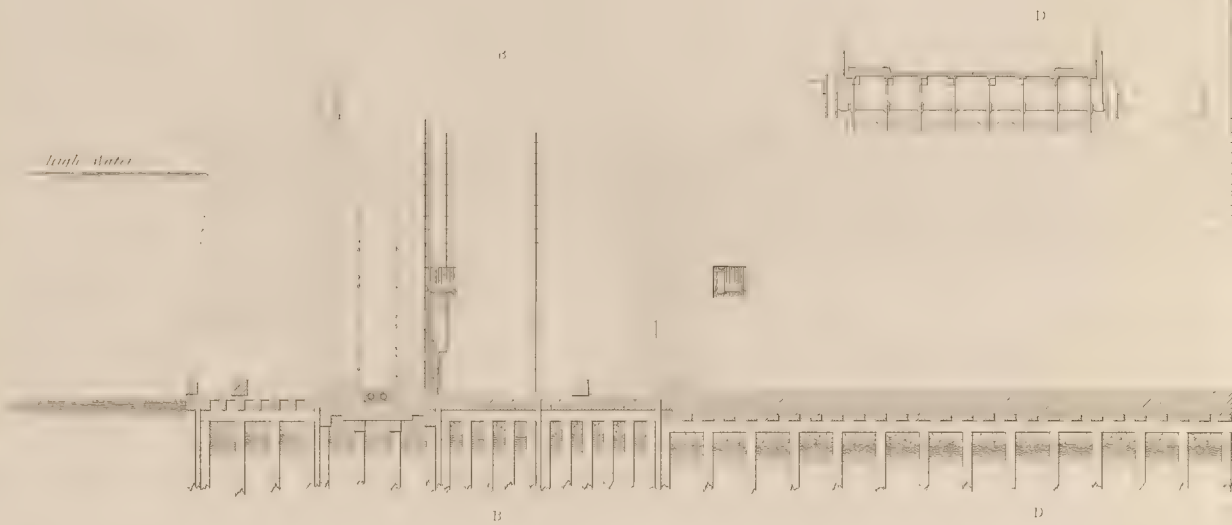
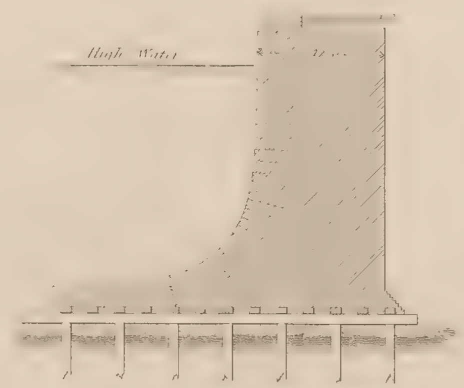
John Weale, Architectural Li

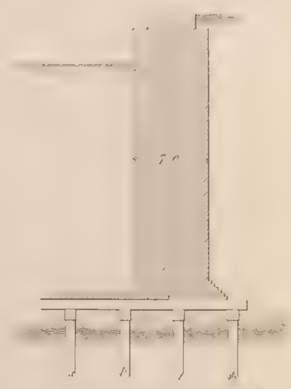

GAS PIPES
OLD DOCK



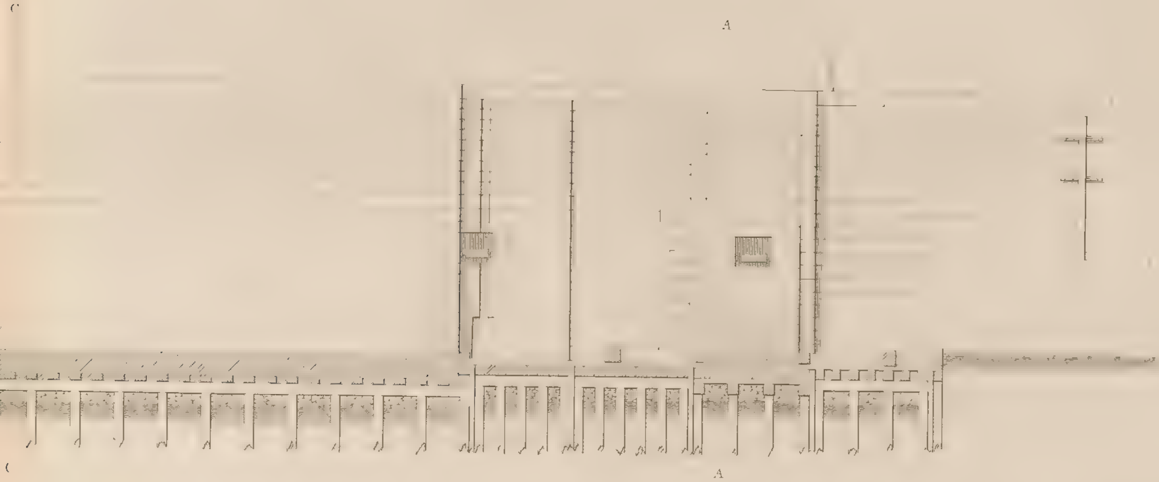
LONGITUDINA



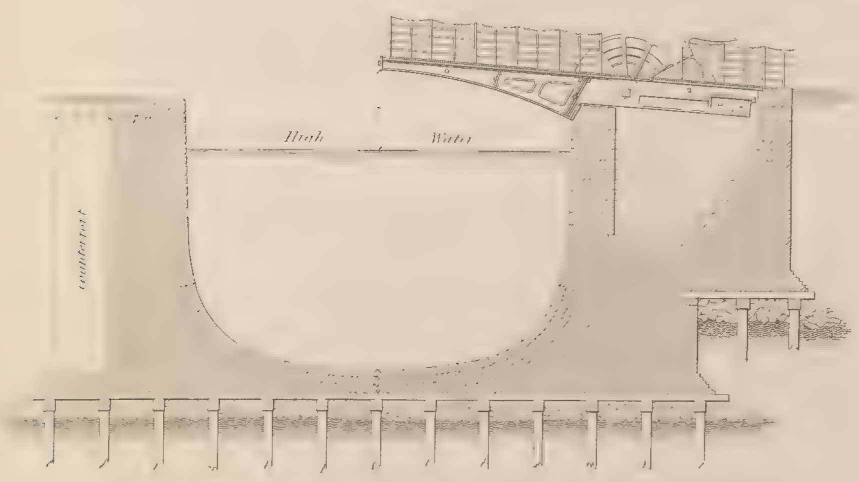
TRANSVERSE SECTION THROUGH A A



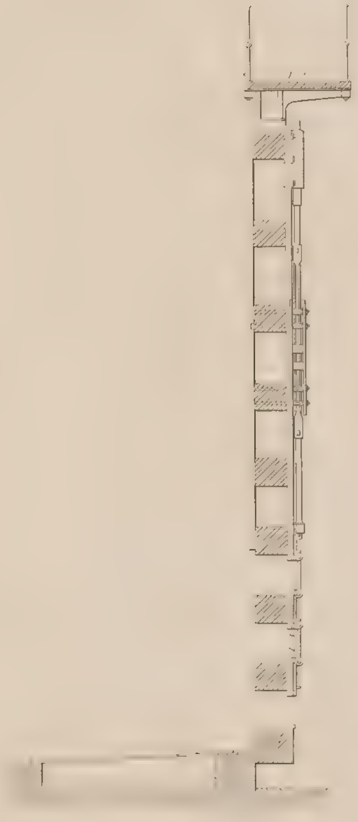
SECTION THROUGH B B



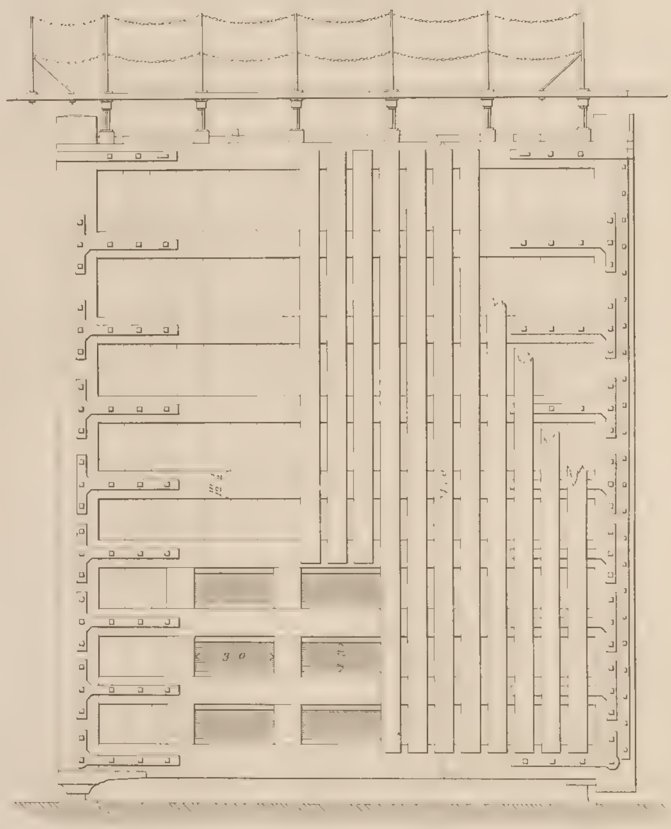
L SECTION



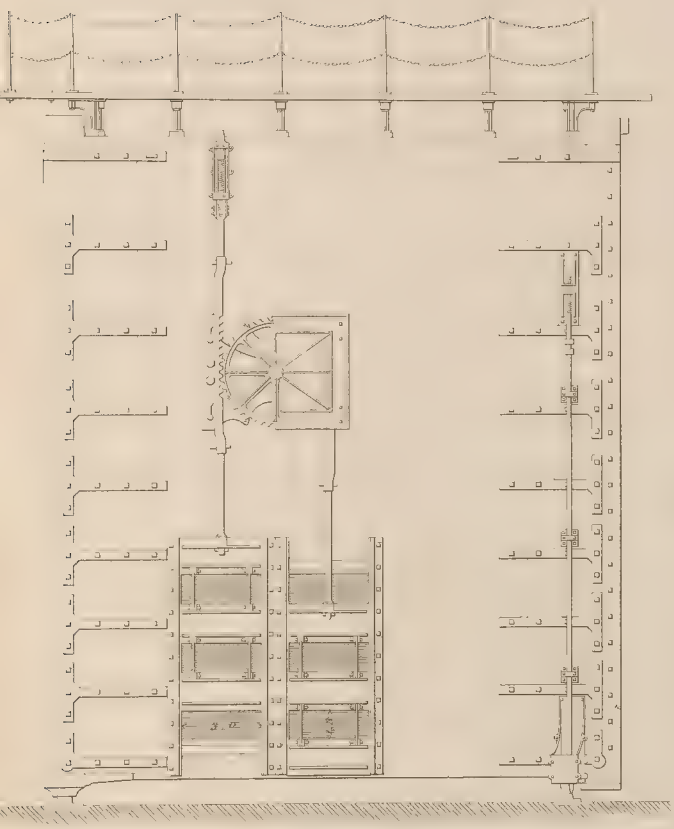
TRANSVERSE SECTIONS THROUGH C.C AND D.D



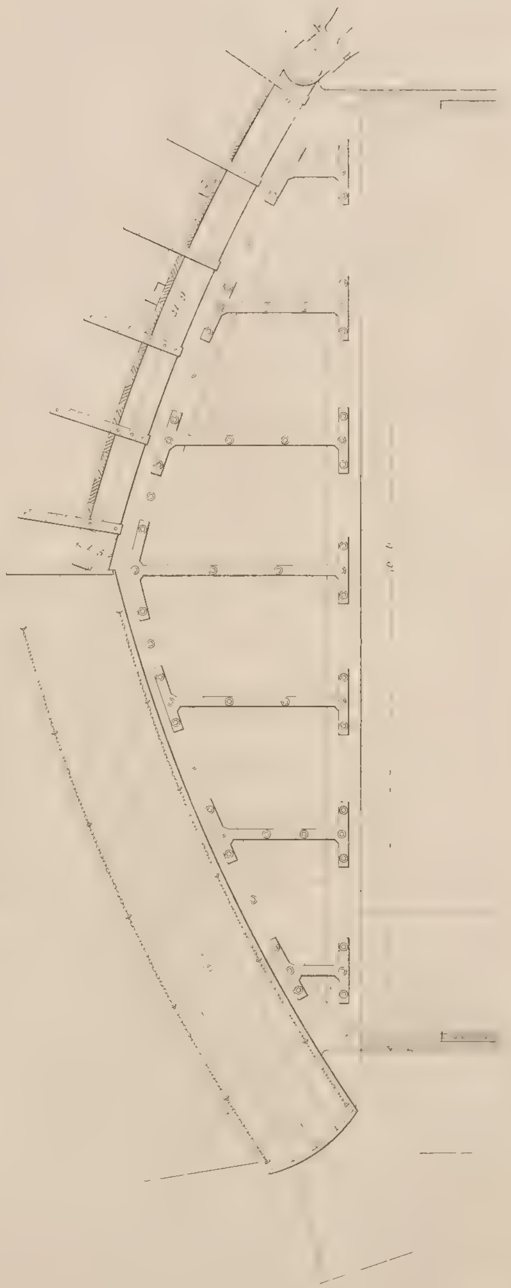
SECTION



ELEVATION OF BACK



ELEVATION OF FRONT.



PLAN

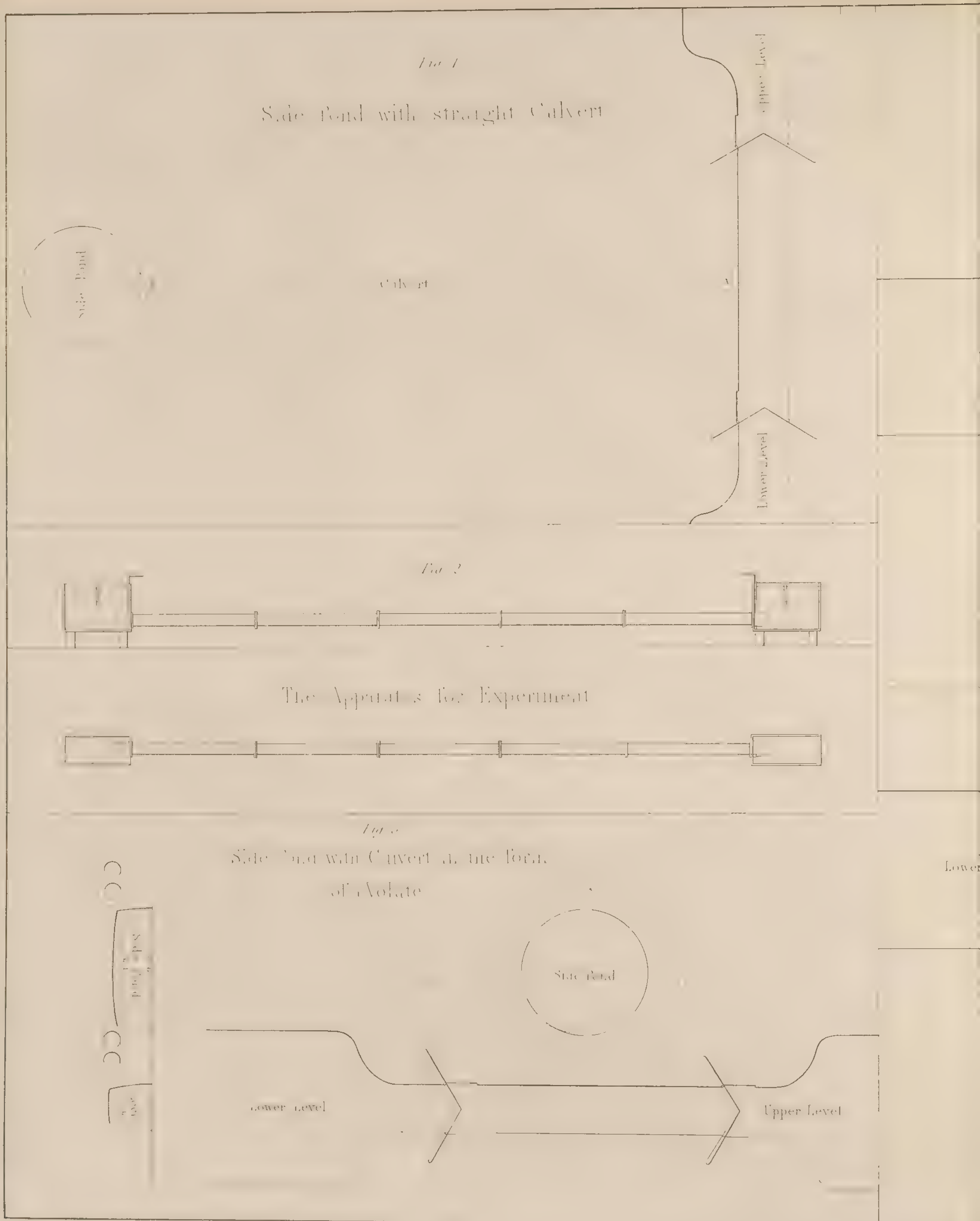


Fig. 1
Side Pond with straight Culvert
Upper Level
Side Pond
Culvert
Lower Level
Fig. 2
The Apparatus for Experiment
Fig. 3
Side Pond with Culvert in the form of Volute
Side Pond
Side Pond
Lower Level
Upper Level

Fig. 4.

Double Locks with Circular Culvert under upper level

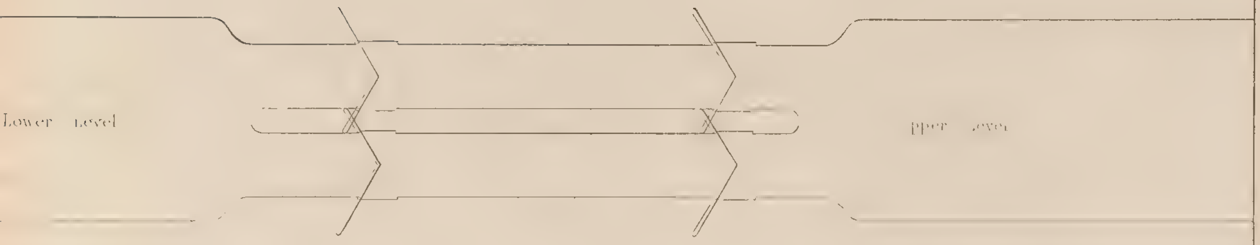
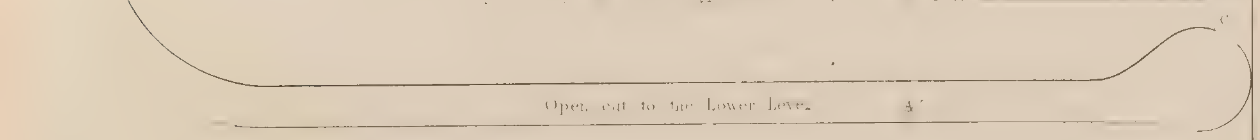


Fig. 5.

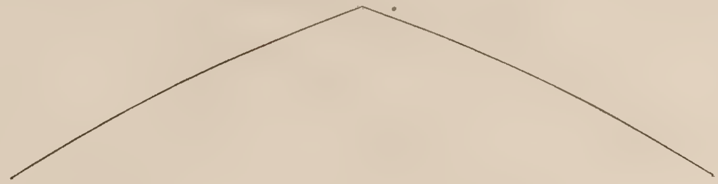
Without a Side Pond



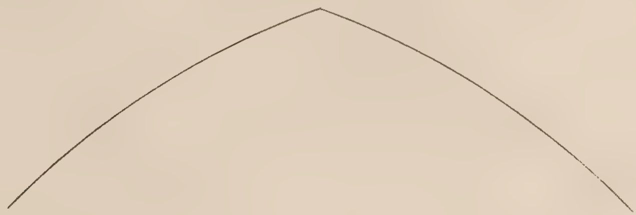
F. Mansell sc

CURVES OF

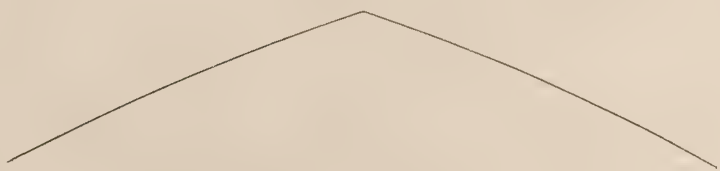
ST KATHERINES DOCKS.



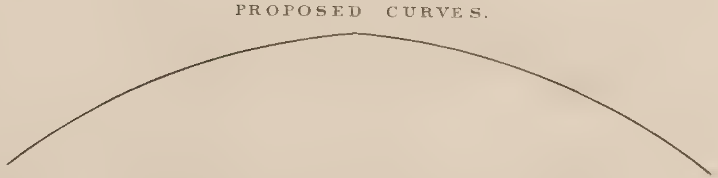
LONDON DOCKS.



WEST INDIA DOCKS.



PROPOSED CURVES.



John Weale, Architectural

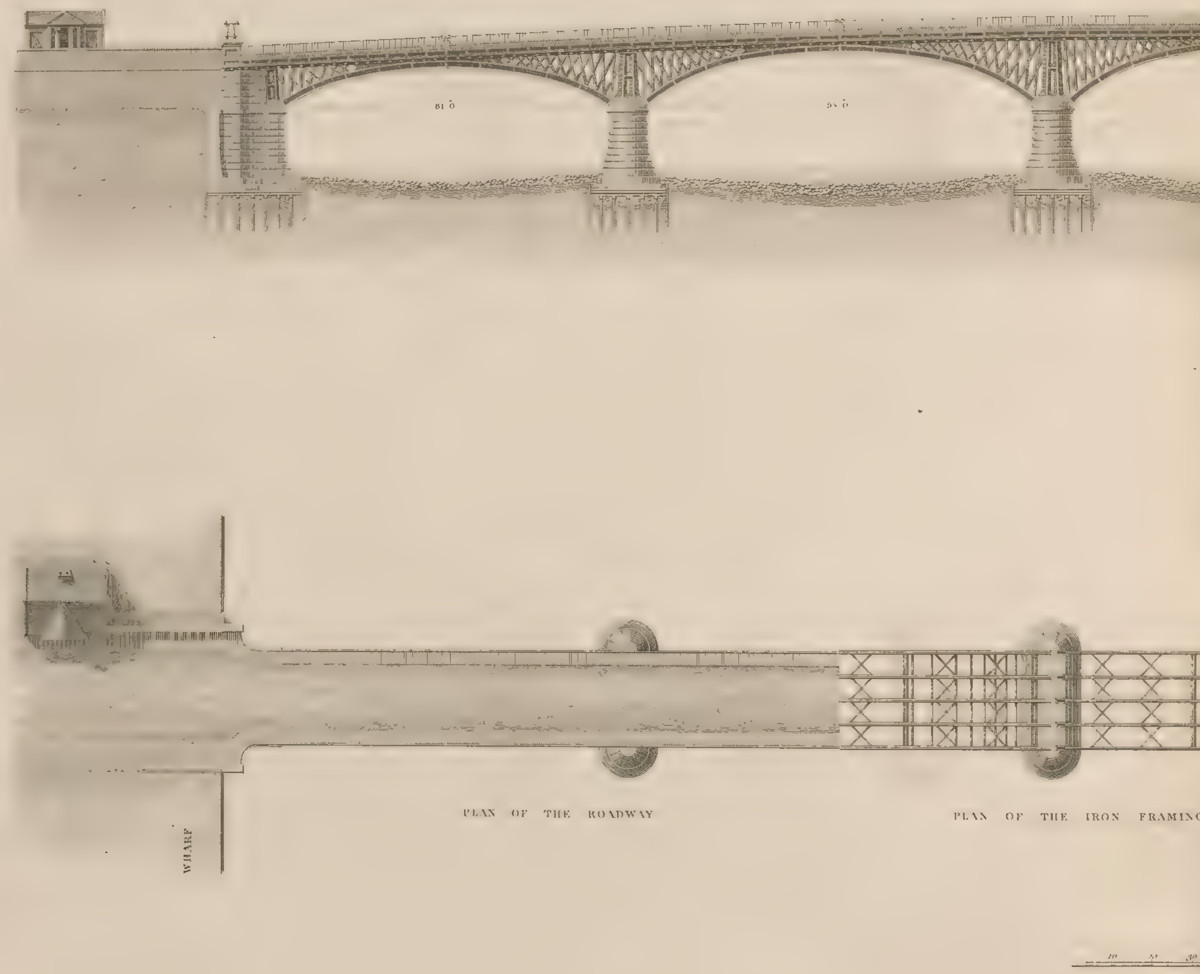
CALEDONIAN CANAL.

SHEERNESS BASIN.

DUNDEE DOCKS.

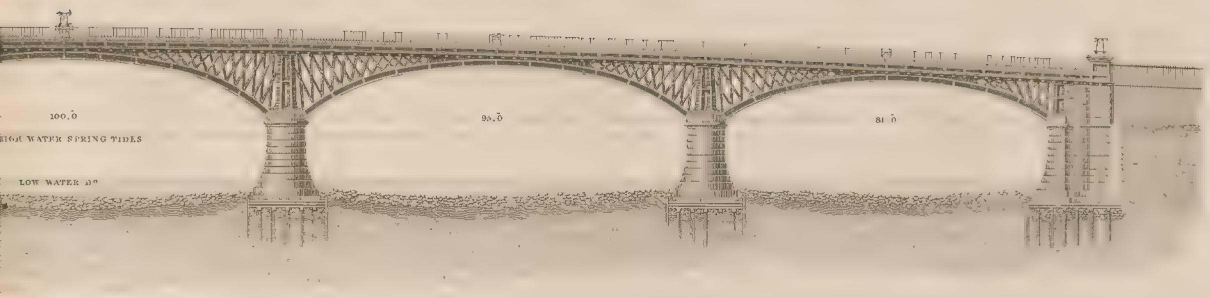
CAST IRON BRIDGE OVER

BY JAMES M. REND



Geo. C. Dobson, del

John Weale, A

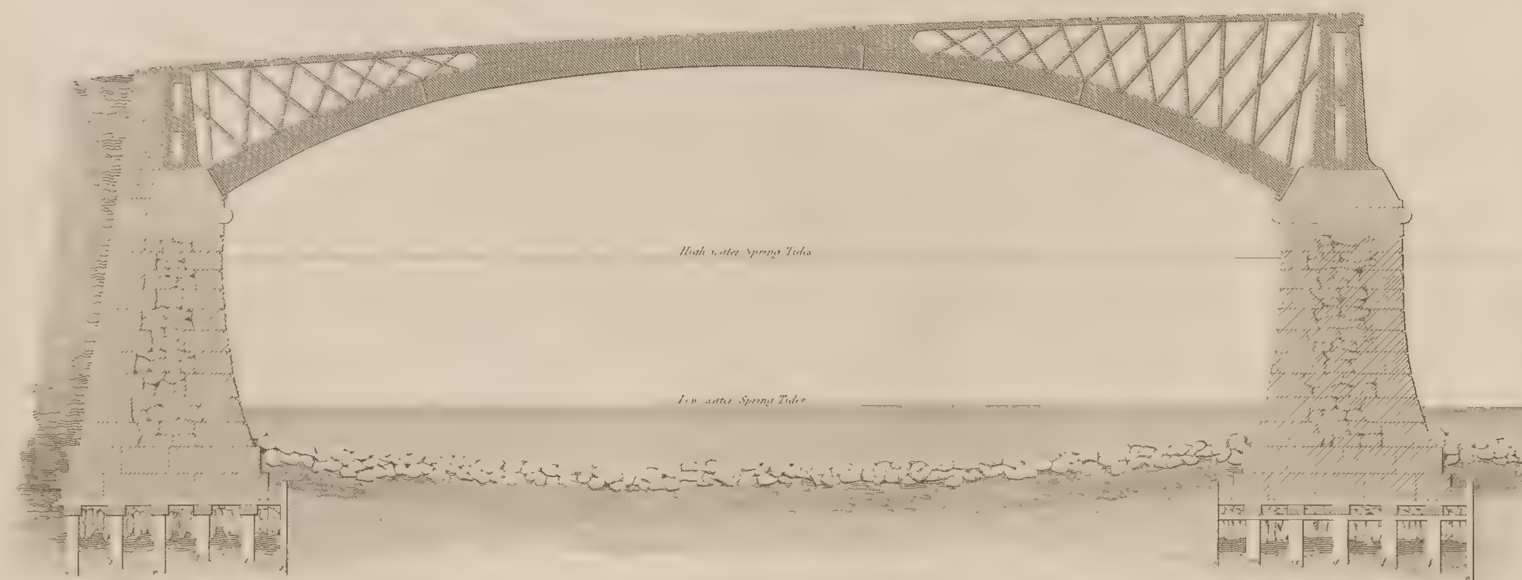


ELEVATION

PLAN OF THE FOUNDATION

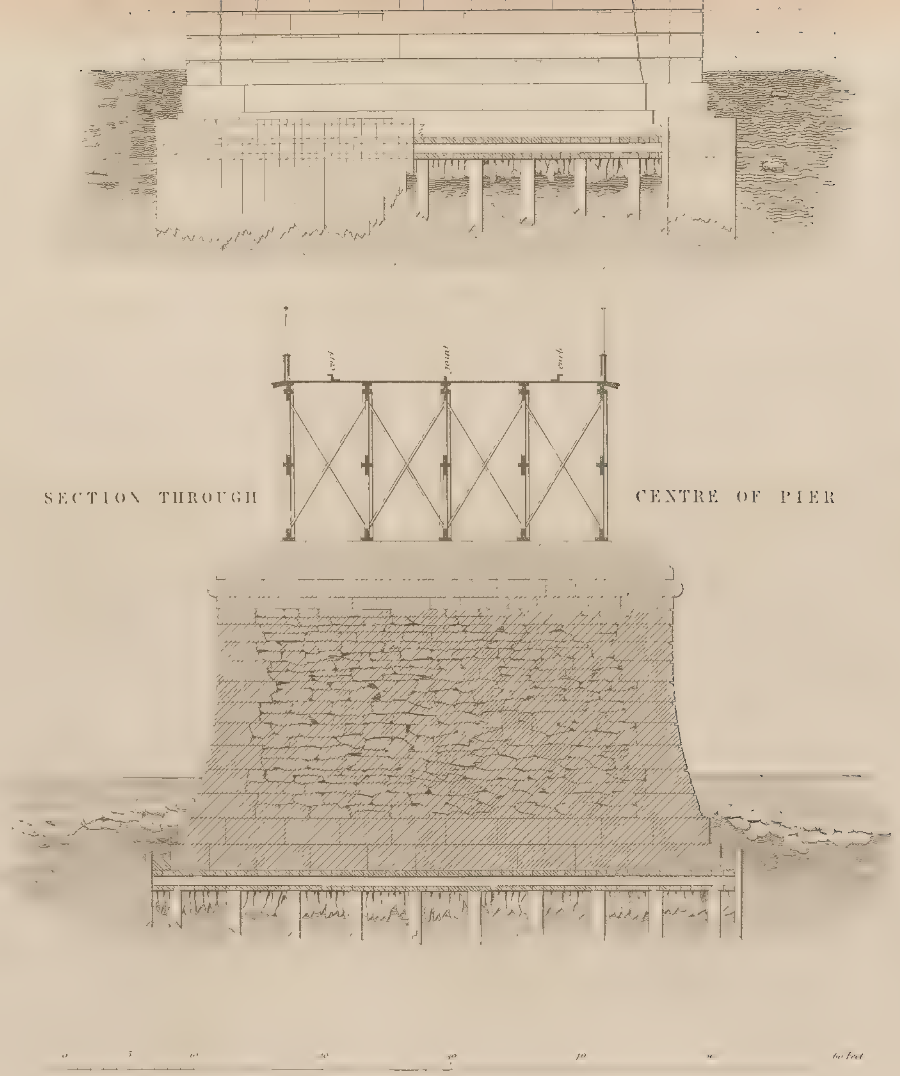
40 50 60 70 80 90 100 feet

LONGITUDINAL SECTION OF ONE OF THE SIDE ARCHES.

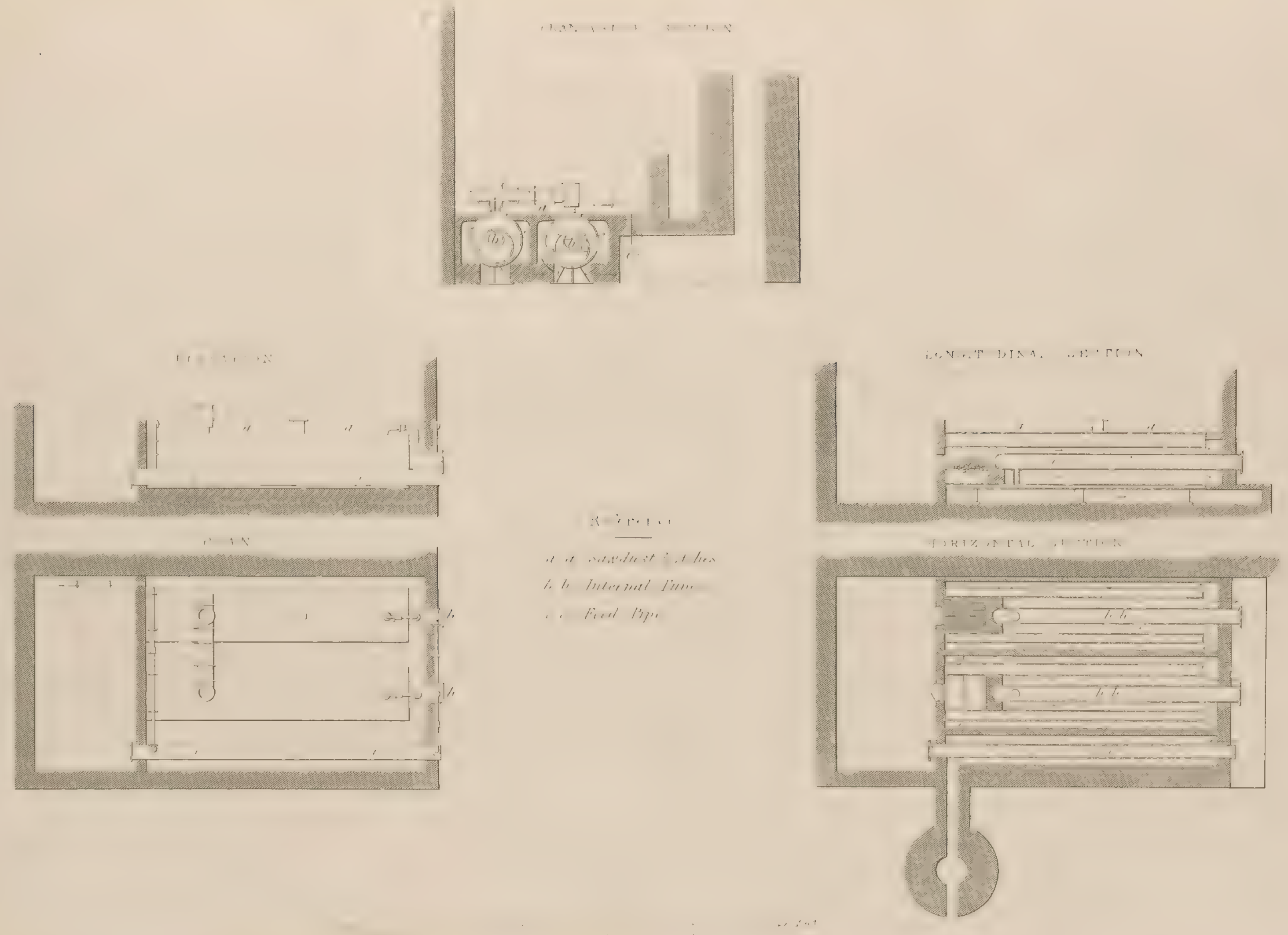


SECTION THROUGH CENTRE OF ARCH

SECTION THROUGH CENTRE OF PIER

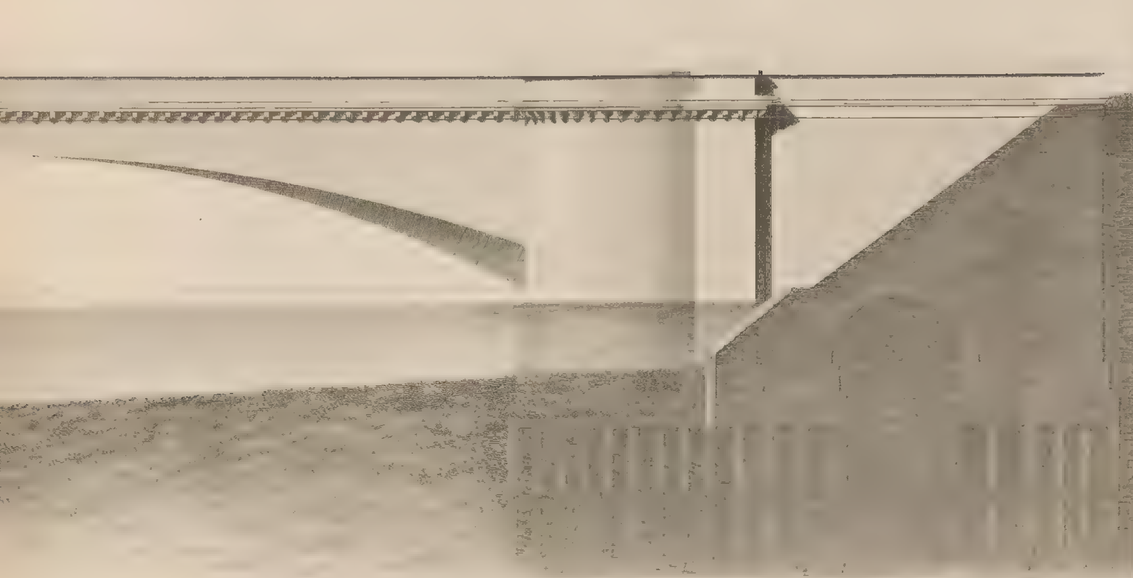


BOILERS OF STEAM ENGINES AS MADE IN CORNWALL.

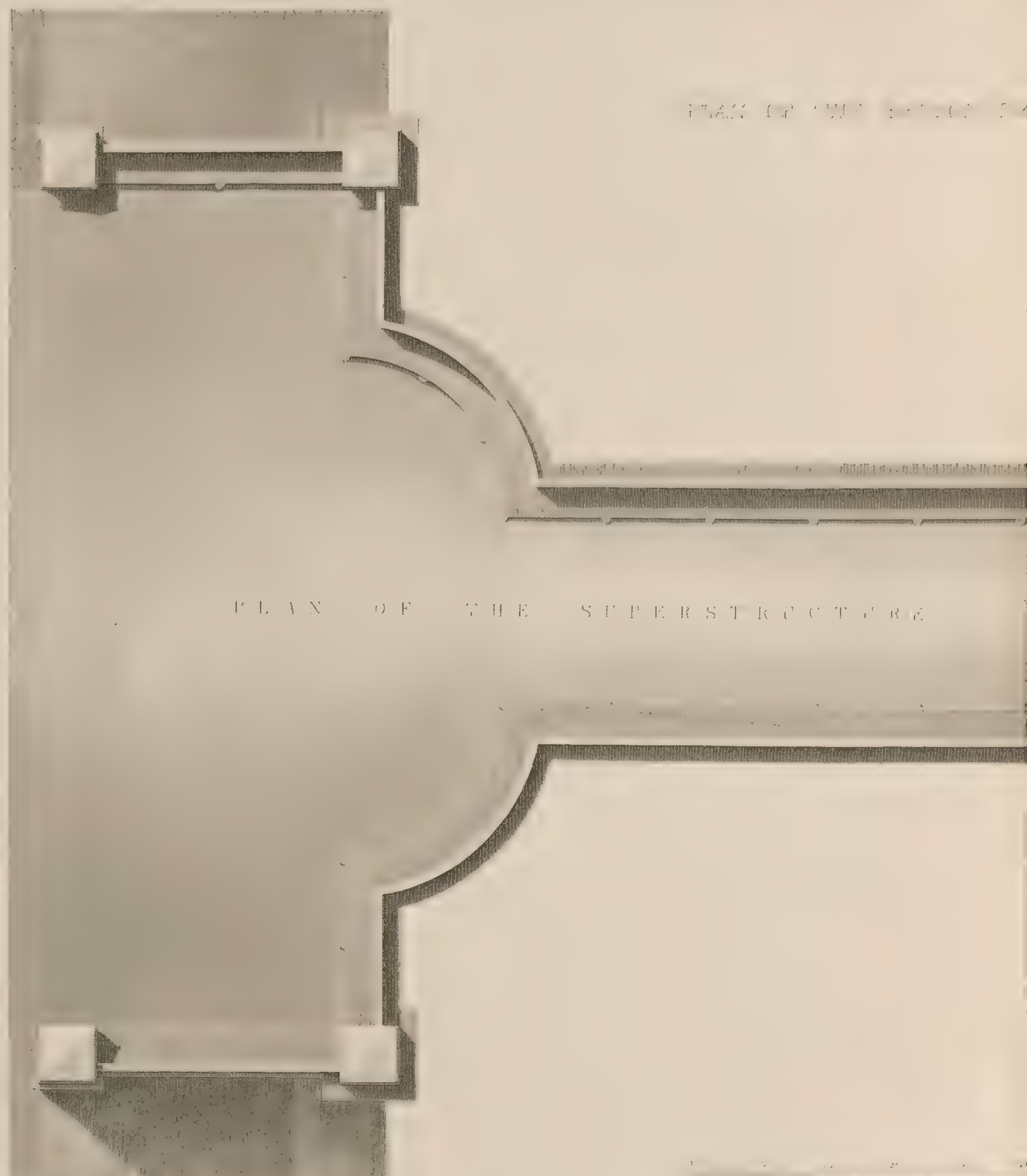


BRIDGE ERECTED OVER

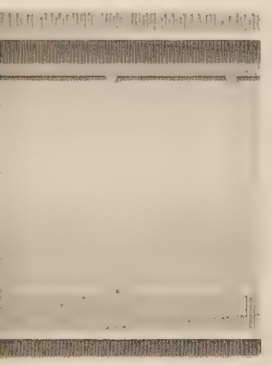
E DORA, NEAR TURIN

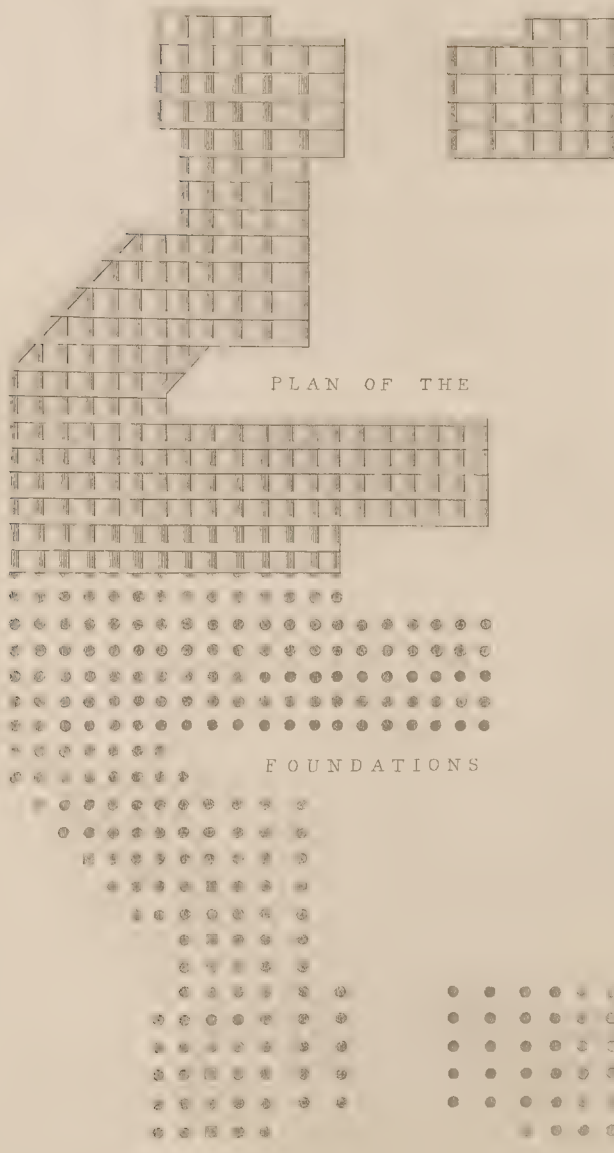


Feet


PLAN OF THE SUPERSTRUCTURE

RECTED OVER THE DORA.





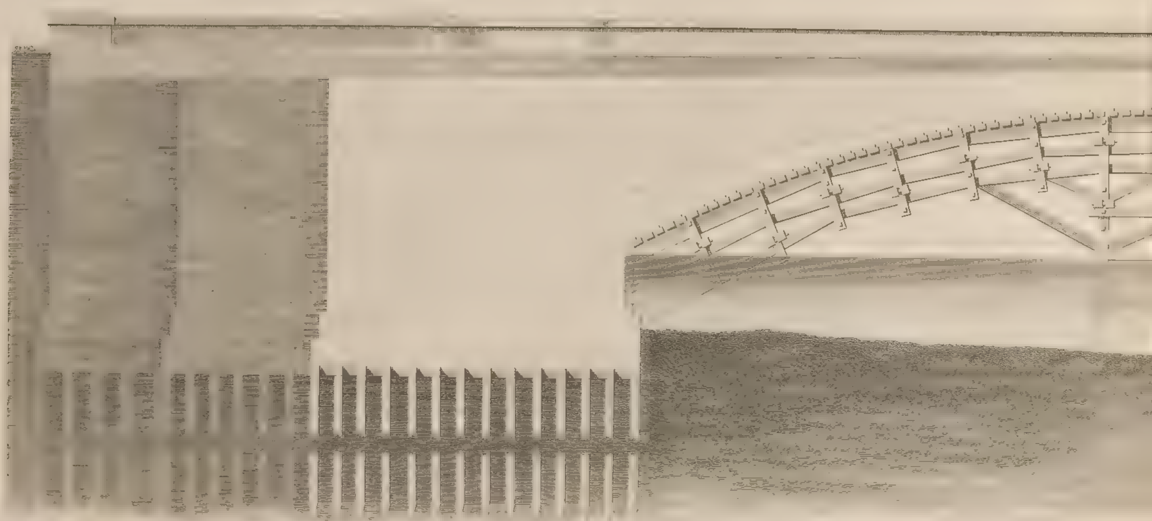
60 90 Feet

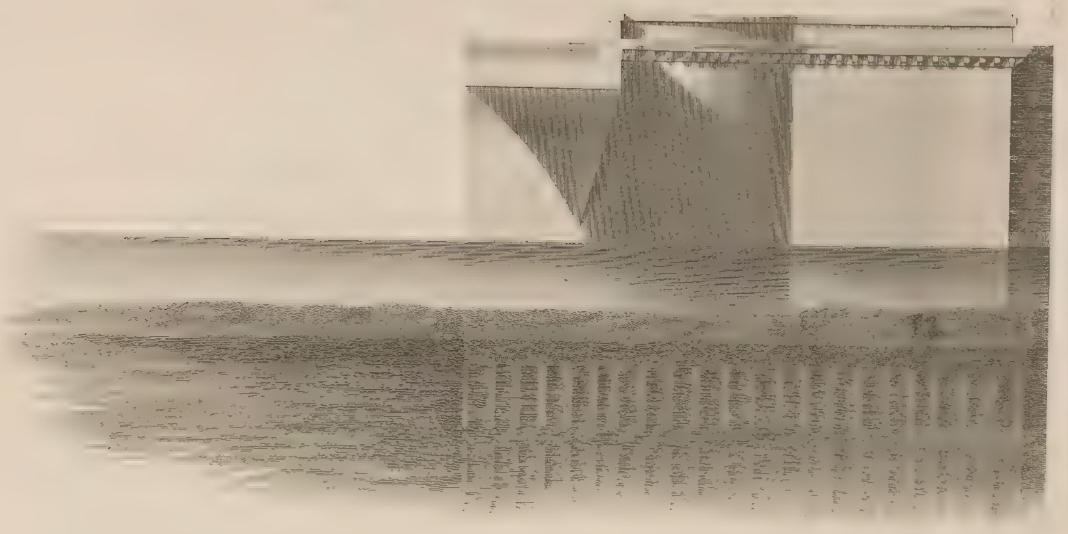
Hawkesworth sc

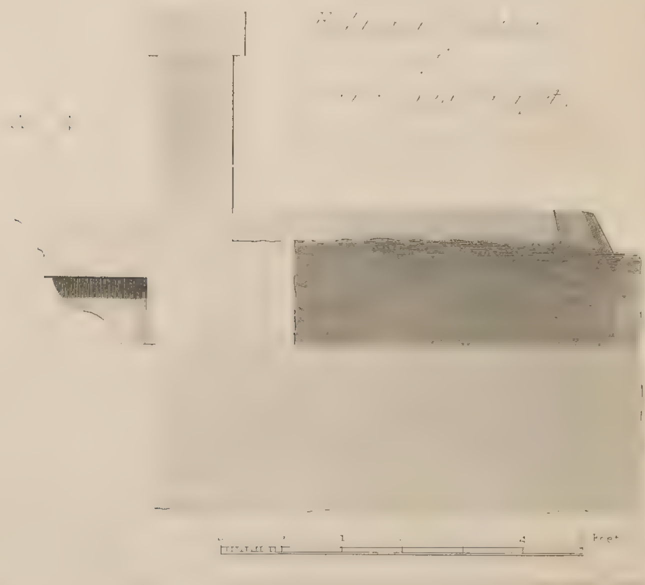
ibrary, 59, High Holborn.

BRIDGE ERECTED OVER

Fig. 1.

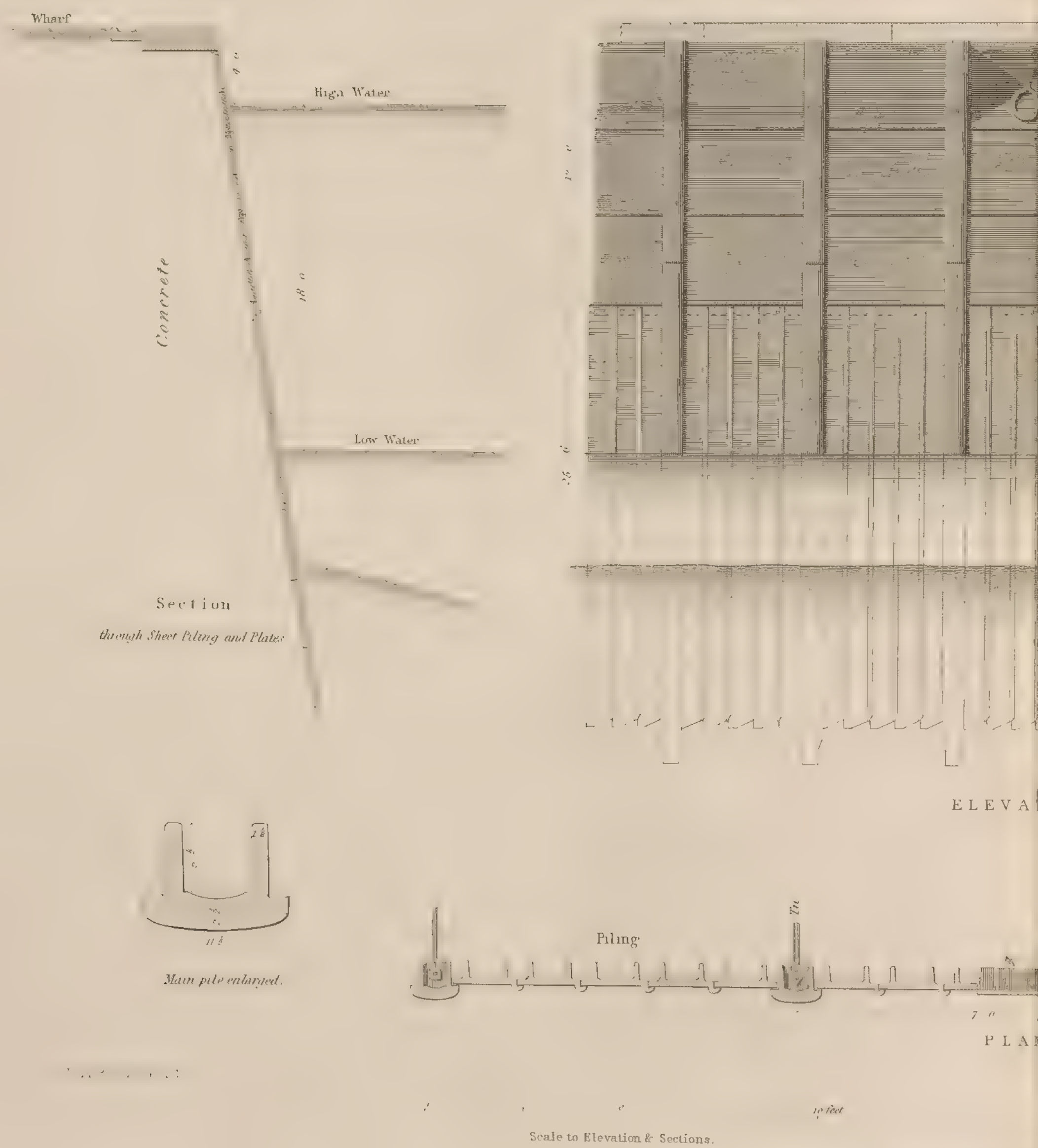




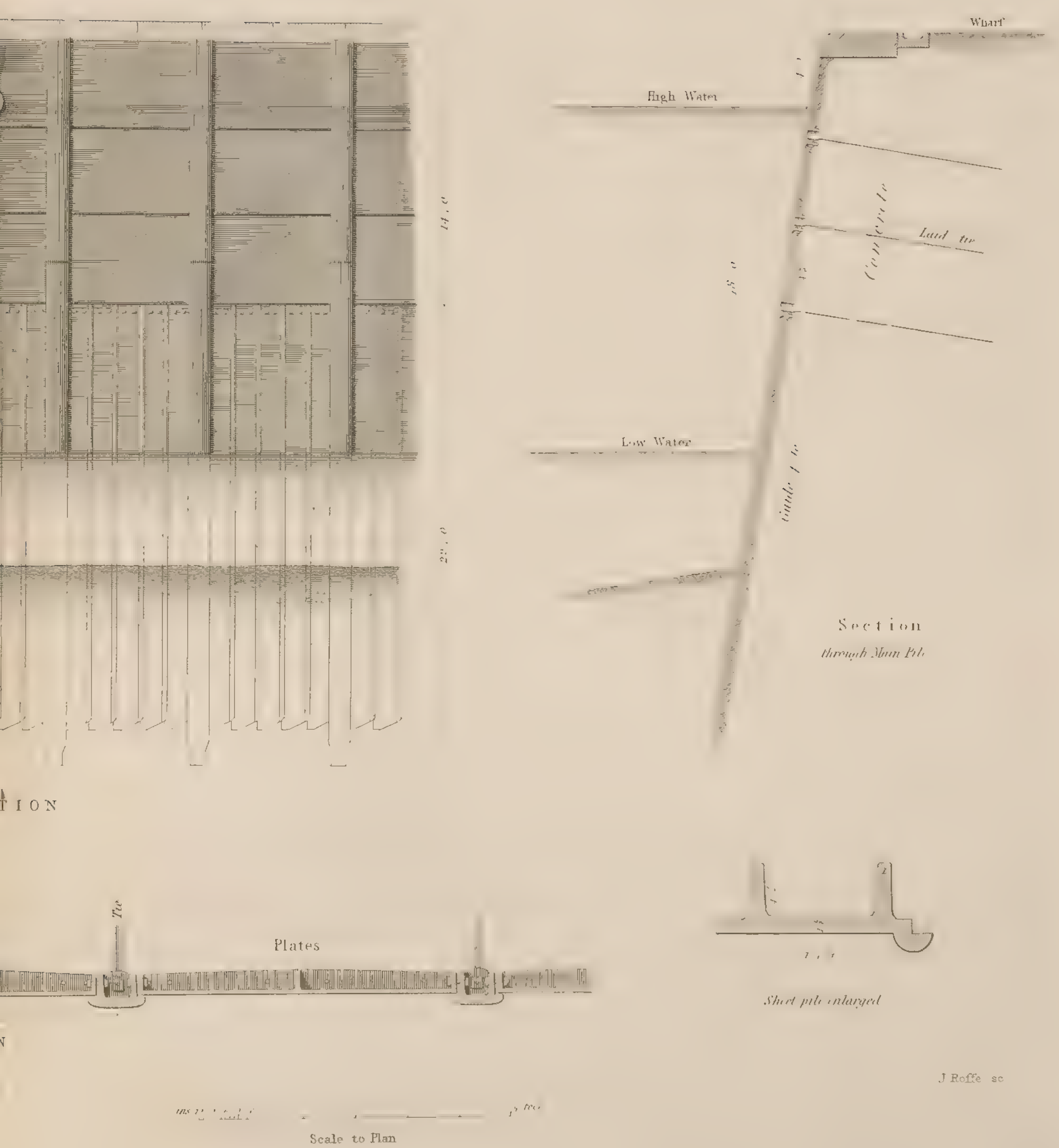


Feet

Feet



Wharf
High Water
Concrete
Low Water
Section
through Sheet Piling and Plates
ELEVA
Main pile enlarged.
Piling
PLA
10 feet
Scale to Elevation & Sections.



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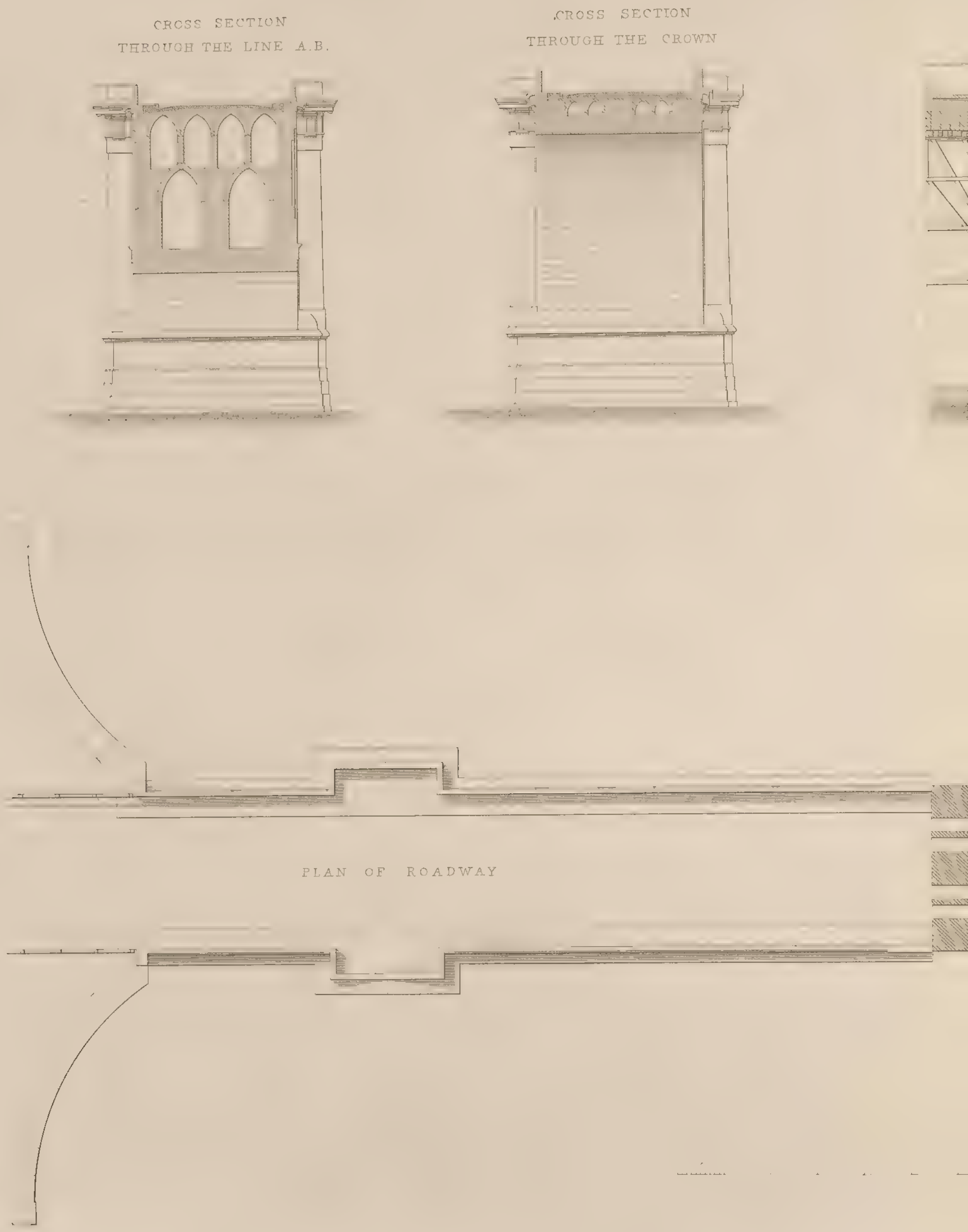

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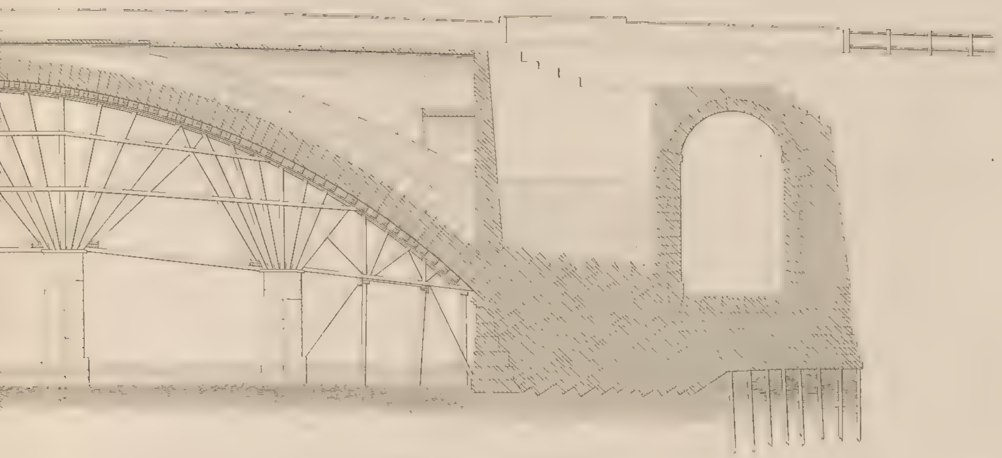
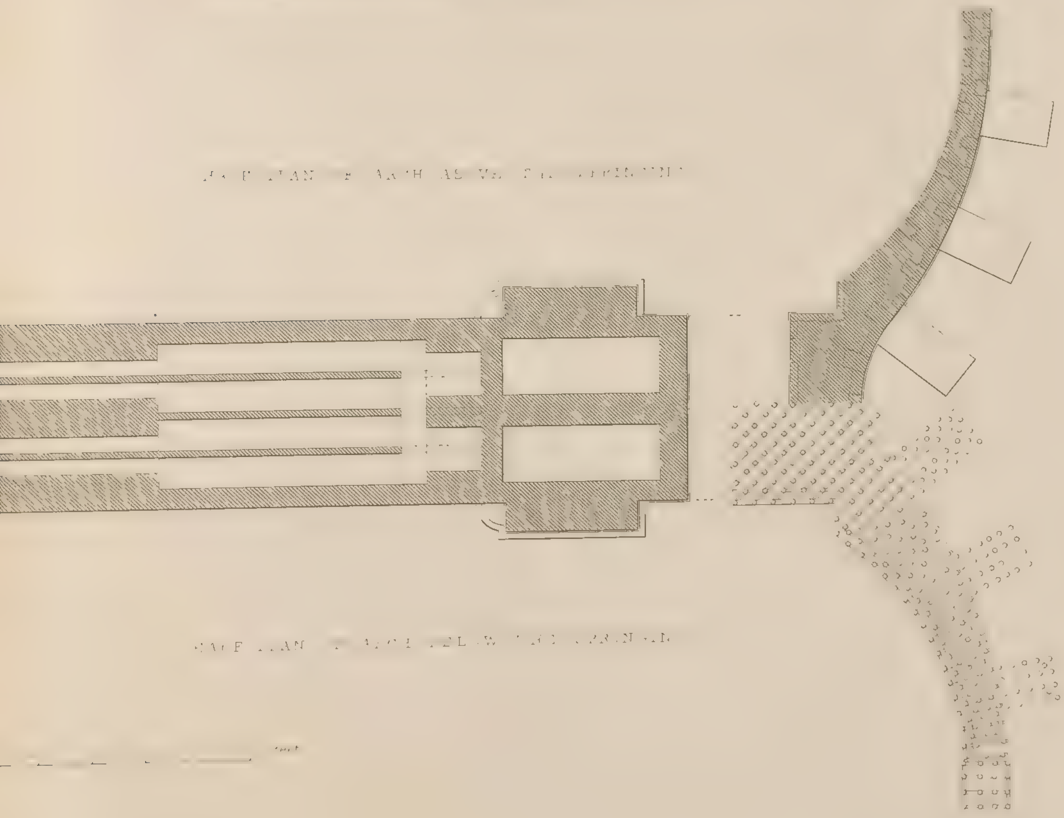
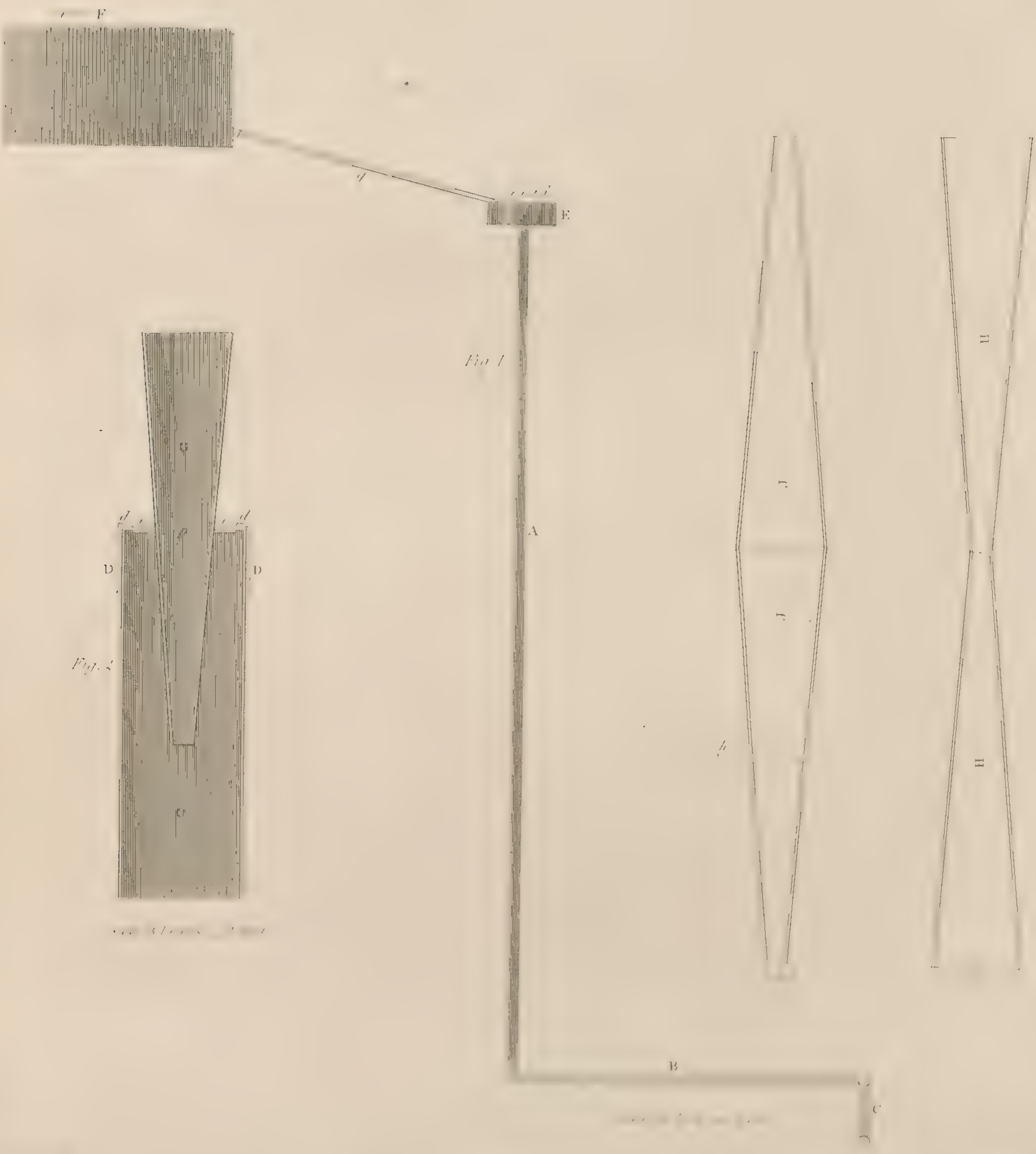
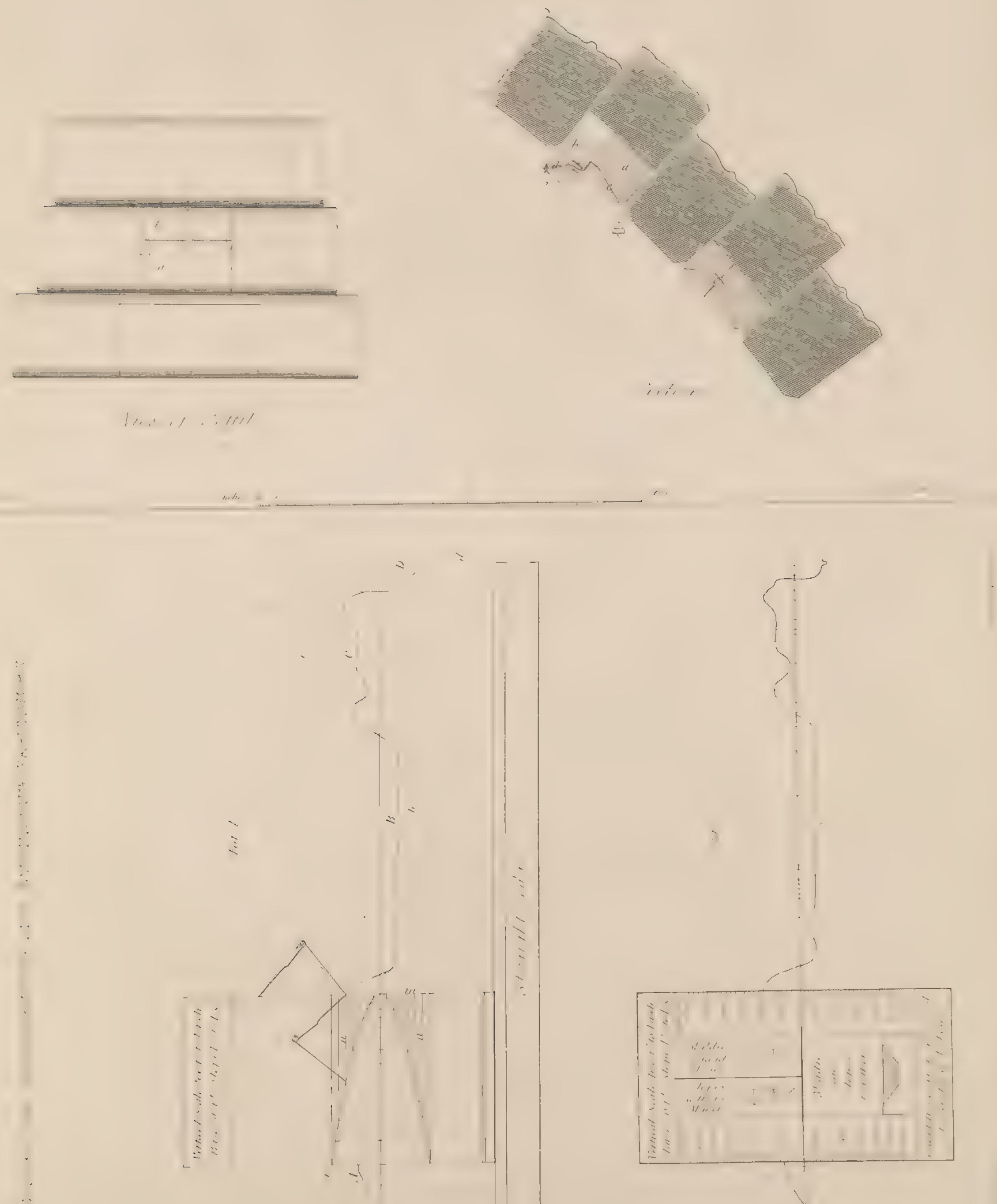
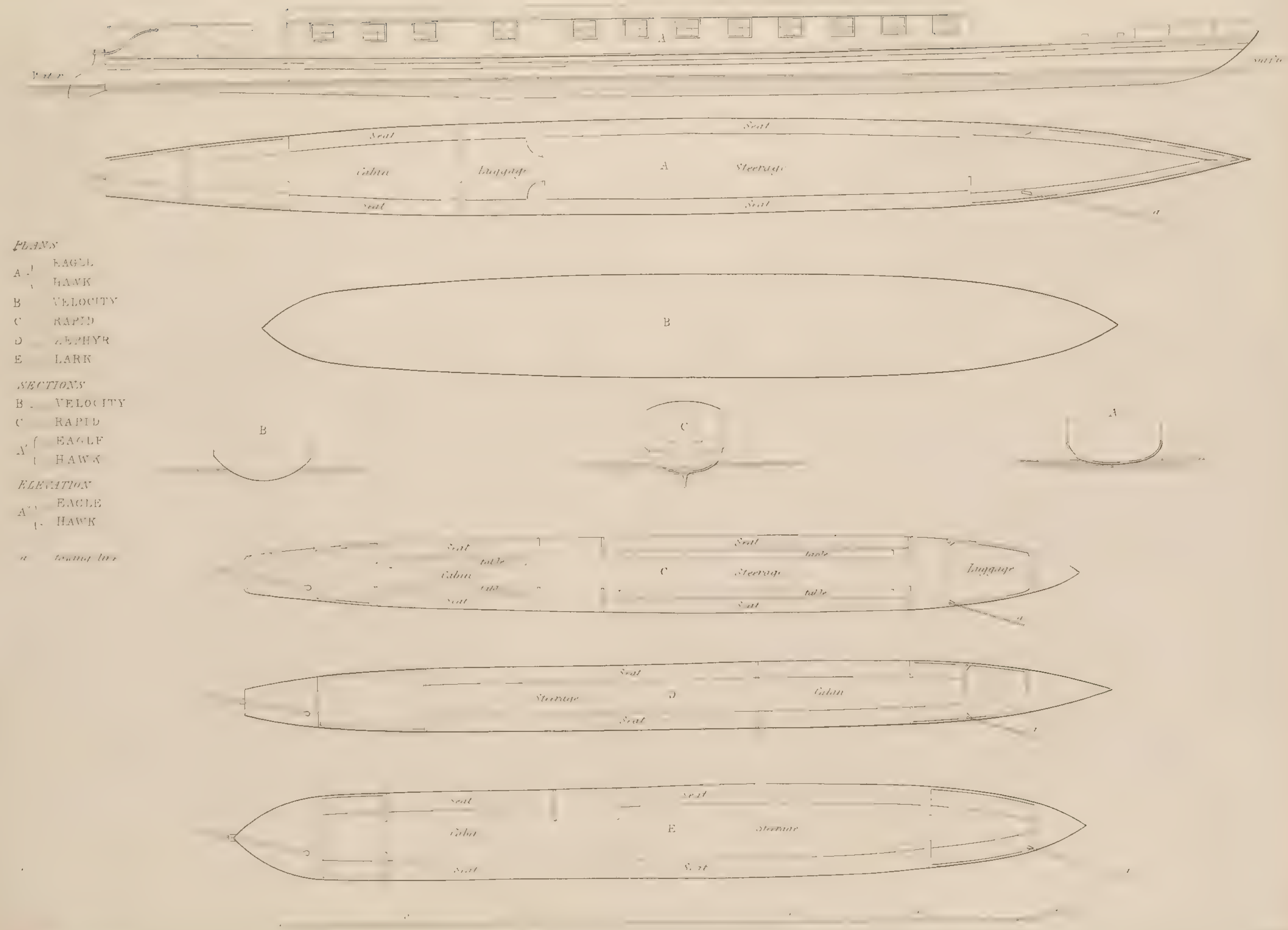






F
E
Fig. 1
A
B
C
Fig. 2
D
D
H
H
J
J




Water
A
Seat
Cabin
Luggage
Steerage
B
C
Table
D
E
PLANS
A { EAGLE HAWK
B VELOCITY
C RAPID
D ZEPHYR
E LARK
SECTIONS
B VELOCITY
C RAPID
A { EAGLE HAWK
ELEVATION
A { EAGLE HAWK

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